Department for International Development

UKaid from the British people

Water, Sanitation and Hygiene

Evidence paper

May 2013

Contents

List of figures, tables and boxes

Tables

Figures

Boxes

Acknowledgements

This Evidence Paper is published by the UK Department for International Development. This is not a policy document, and does not represent DFID's policy position.

The following people worked on the preparation of this Evidence Paper:

From the London School of Hygiene and Tropical Medicine and the SHARE research programme consortium:

Sandy Cairncross, Oliver Cumming, Aurelie Jeandron, Rick Rheingans, Jeroen Ensink, Joe Brown, Sue Cavill, Sally Baker and Wolf-Peter Schmidt.

From DFID:

Jenny Amery, Simon Bibby, Matthew Harvey, Guy Howard, Jo Mulligan, Helen O'Connor, Lily Ryan-Collins, Peregrine Swann, Sanjay Wijesekera and David Woolnough.

The paper has been peer-reviewed by experts in the field. We would like to thank the following who kindly reviewed all or parts of this paper:

Prof Jamie Bartram (University of North Carolina at Chapel Hill), Prof David Bradley (University of Oxford), Prof Simon Brooker (London School of Hygiene and Tropical Medicine/Kenyan Medical Research Institute), Prof Daniel Chandramohan (London School of Hygiene and Tropical Medicine), Prof Jean Humphrey (Johns Hopkins University), Prof Paul Hunter (University of East Anglia), Dr Rick Johnston (EAWAG), Prof Kumarjyoti Nath (All-India Institute of Public Health & Hygiene).

Any errors or omissions remain those of the authors.

Every effort has been made to give a fair and balanced summary. In some areas where the evidence base is not clear-cut there is inevitably a subjective element. If readers consider that the evidence on any issue is not accurately described or misses important studies which may change the balance, please let us know by emailing waterresearch@dfid.gov.uk so that we can consider this when correcting or updating the paper.

Acronyms

ARI	Acute Respiratory Infections
CLTS	Community-led Total Sanitation
DALYs	Disability-Adjusted Life Years
DFID	Department for International Development
GRADE	Grading of Recommendations Assessment, Development and Evaluation
HACCP	Hazard Analysis, Critical Control Point
HWWS	Handwashing with soap
JMP	WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation
LiST	Lives Saved Tool, evidence-based tool for estimating intervention impact
MDA	Mass Drug Administration
MDG	Millennium Development Goal
MHM	Menstrual Hygiene Management
PLWHA	People Living With HIV/AIDS
PMTCT	Preventing Mother To Child Transmission of HIV
POU	Point Of Use
PRA	Participatory Rapid Appraisal
RCT	Randomised Controlled Trial
SHARE	Sanitation and Hygiene Applied Research for Equity
SHEWA-B	Sanitation, Hygiene Education and Water Supply in Bangladesh
UNICEF	United Nations Children’s Fund
WASH	Water, Sanitation and Hygiene
WSP	Wastewater Stabilisation Ponds
WHO	World Health Organization

Executive Summary

The following section provides an executive summary of this paper, highlighting the key findings in relation to the priority areas identified by DFID.

The paper sets out the methods for this review and the approach for assessing the strength of evidence. The different bodies of evidence reviewed in this paper have been graded as 'good', 'suggestive, and 'weak' as per the criteria below:

• **Good evidence**: several good quality studies that consistently show an effect. For example, randomised trials with a low risk of bias or observational studies showing a large effect size with a low potential for confounding

• **Suggestive evidence**: studies which show an effect but statistical support is weak due to insufficient study size. Or, studies which show significant effects but there is a risk of bias and confounding

• **Weak evidence**: no studies have been done or, where they been done, they have shown inconclusive results

A summary assessment of the evidence underlying the impact of the four main Water, Sanitation and Hygiene (WASH) interventions on diarrhoea according to seven 'points of view' is also scored as 'favourable', 'intermediate' and 'unfavourable'. This shows the degree to which, from each viewpoint, the available evidence supports or undermines the case for implementation of each intervention. The scoring given for each cell of the table reflects the individual gradings given for the strength of evidence throughout this paper. Thus, this table summarises the variation in the strength of the evidence base of the WASH sector:

1. Evidence on impact

Several systematic reviews have assessed the impact on health of a range of WASH interventions. The studies reviewed are classified in different ways and include a range of outcome indicators, but the most common of these is diarrhoeal disease morbidity.

The impacts associated with WASH extend beyond health, although in general the evidence is less well developed.

The key points from a review of the evidence on both the health and non-health impacts as presented in sections 4-7 are given below:

Health Impacts

• The World Health Organization (WHO) – based on suggestive evidence – estimates that approximately 2.4 million deaths and 7% of the total disease burden could be prevented annually with safe WASH

• It is estimated that diarrhoea diseases are now the leading cause of child deaths in Africa and the second leading cause of child deaths globally. There is good evidence that inadequate WASH contributes substantially to this mortality burden

• There is good evidence that the health impacts of WASH extend far beyond diarrhoea to include many other important diseases including: acute respiratory infections, undernutrition, soil-transmitted intestinal helminth infection (ascaris, trichuris and hookworm), schistosomiasis, Guinea worm, trachoma and certain non-infectious diseases associated with chemical water quality (arsenicosis and fluorosis)

• There is good evidence that improved hygiene can reduce the risk of acute respiratory infections (pooled estimate of 23% risk reduction)

• There is suggestive evidence that diarrhoea (as a consequence of inadequate WASH) contributes to undernutrition but there is currently weak evidence for causal links to tropical enteropathy

• There is an unequal distribution of WASH-associated mortality and morbidity with disproportionately high levels among the poorest populations and the majority of deaths from diarrhoea occurring among children

Non-health impacts

• There is good evidence that improved WASH is associated with significant time savings and that this is highly valued by service users

• Most of the available evidence on the effect of WASH on education and gender is based on anecdote, circumstantial evidence and small observational studies; statistically the evidence appears weak. Despite this, what little direct evidence exists confirms the view that the non-health benefits of WASH interventions are substantial

• It is plausible that inadequate WASH inhibits school attendance, especially among girls, but a DFID-funded systematic review of the peer-reviewed literature found that there was no strong evidence either for or against this hypothesis. Current randomised trials in Kenya and India may shed more light on this important issue

• There is good evidence that lack of access to water continues to impact women significantly through the burden of water collection. Household survey data collected from over 40 countries showed that women carry two-thirds of the burden for water collection

• There is suggestive evidence that women in particular suffer a range of impacts associated with poor sanitation, including violence and insecurity, but more rigorous research is required to understand and quantify the associated risks

• Whilst anecdotal evidence suggests that inadequate provision for menstrual hygiene management leads to reproductive tract infections and urinary tract infections, more work needs to be done to build the currently weak evidence base for this

2. Evidence on delivery options

There is limited rigorous evidence regarding the best choice of specific delivery models for WASH. Whilst the systematic review literature on WASH and diarrhoea is useful for understanding the epidemiology of WASH, it provides less insight as to the most effective options for delivering efficacious interventions at scale.

This review has not considered specific approaches or technologies due to a lack of systematic data evaluating their effectiveness, but also due to the variation in the implementation of specific approaches or technologies across different settings. This review notes the consistent features of good WASH programmes rather than judge between alternative models. Most of this evidence is suggestive only.

The following are points identified in the review and discussed in more detail in section 8:

• There are so few well documented case studies of WASH programmes at scale that it is difficult to draw an evidence-based conclusion as to the most effective approaches

• There is suggestive evidence that formative or market research is particularly important for interventions that require changes in behaviour (especially handwashing with soap and sanitation)

• There is limited suggestive evidence that careful targeting of subsidies in order to leverage household investment can contribute to an increased likelihood that a toilet is used and maintained

• There is some limited suggestive evidence that toilets designed to a target price and for a market niche can be more effective in attracting household investment

• There is conflicting evidence as to the effectiveness of shared sanitation facilities although this may be explained by the many models or approaches that this term encompasses. Whilst there is suggestive evidence that shared facilities managed by communities function well (as opposed to privately managed facilities), there is other suggestive evidence that usage of shared facilities – whether community or privately managed – was significantly lower among women than men

• There is good evidence that for urban on-site sanitation systems to be effective they must allow for pit-emptying, or at least replacement of the pit, and the safe disposal of the pit contents where necessary

• There is suggestive evidence that health outcomes improve (as a consequence of increased use of water) when the water source is closer to the household with the implication that water supply strategies should take account of distance to source and plan and invest accordingly

• There is suggestive evidence that sustainability is a major challenge for WASH services with facilities falling into disuse or disrepair over time

3. Evidence on cost-effectiveness and value for money

There is good evidence that WASH investments can have significant health, economic and development benefits and that these investments may be at a level that is comparable or favourable to other interventions in term of cost-effectiveness.

However, the existing evidence is generally inadequate to determine whether WASH investments are significantly more or less cost-effective than other interventions, given uncertainty and the variability in benefits across settings. Overall, a review of evidence suggests that the sector currently lacks the necessary information to maximise the return and value for investments.

In summary from section 9, the key points relating to the economics of WASH from the available evidence are:

• There is limited systematic data on the costs of providing and sustaining WASH services

• Overall, current estimated costs provide only suggestive evidence for the actual costs associated with WASH interventions and should be viewed with caution as they do not provide breakdowns for costs based on settings or based on conditions

• There is some evidence on the economic benefits, but authors acknowledge that data are limited in estimating these benefits and rely on significant assumptions in order to generate preliminary estimates

• Better evidence would involve experimental designs that empirically measure economic and financial improvements in communities or individuals receiving water, sanitation or hygiene. There is little existing evidence of this type due to the methodological challenges of conducting these kinds of trials

• Most global cost-effectiveness and cost-benefit analyses focus on diarrhoea as the outcome and therefore do not include potential impacts on soil-transmitted helminths, nutrition, adolescent sexual health, maternal mortality and schistosomiasis. This can result in an underestimate of the value for money of WASH interventions. However, it can also result in inconsistent and biased estimates making it difficult to compare the cost-effectiveness of different WASH interventions and to compare WASH interventions to other health and development interventions

• A benefit estimate approach suggests that the estimated monetary value of all of the scenarios provides excellent value for money in all contexts, with the economic value of returns greatly exceeding costs. These estimates would be greatly improved with improved empirical data regarding the assumptions of economic benefits or from rigorous studies that directly measure economic outcomes

• Current estimates of economic and health benefits of WASH interventions do not utilise existing best practices for estimating uncertainty regarding quantitative benefit estimates. Probabilistic simulation methods have been recommended and these should be used for estimating the impacts of WASH interventions in an objective manner

• In addition to improving the accuracy of estimates there are several areas in which improved economic evaluation information could directly result in improved efficiency of investments and value for money. In particular there is very little evidence to guide decision makers about how to invest efficiently within the sector at a given scale (local, national or regional)

4. New evidence – what we need to know to do better

As with most areas of health and development, there are a number of gaps in our understanding of the magnitude and mechanisms of the impact of WASH interventions. Achieving a better understanding of these through rigorous research that harnesses a range of research methods and approaches will build stronger policy and programmes.

In summary from section 10 where they are discussed in more detail, the following key gaps in the evidence are identified:

• Relative effectiveness and efficacy of sanitation interventions on health

• Environmental transmission of excreta-related infections and the role of different pathways

• The effect of enteric exposures on multiple health and developmental outcomes

• Non-health impacts associated with poor WASH, especially for the long-term

• How vulnerable populations are affected and how they can be reached

• Behaviour change for hygiene and sanitation, especially at scale

• Costs and cost-effectiveness across social and physical settings

In section 10, a small number of enduring research questions were identified during the course of this review. The list is far from exhaustive and each could give rise to a list of applied or basic research questions:

1. What are the dominant excreta-related disease transmission pathways in particular contexts and how does this influence the selection of intervention strategies?

2. How can genetic and epi-genetic patterns be used to develop improved interventions?

3. What are the methods for designing effective and locally relevant at-scale behaviour change interventions for a given context?

4. What are the health and development impacts of WASH interventions throughout the life-course, and how can they be maximised?

5. What interventions and delivery options work where and why? And, how can they be adapted to different settings?

1. Introduction

1.1. Aims of the Water, Sanitation and Hygiene (WASH) Evidence Paper

This paper was commissioned by the DFID Water and Sanitation and Research and Evidence Division (RED) Teams and undertaken by the DFID-funded Sanitation and Hygiene Applied Research for Equity (SHARE) research programme consortium.

DFID has undertaken evidence papers addressing a range of development sectors and interventions and their purpose is described as:

"...to support the development of business plans, policy frameworks and relevant country programmes. They draw on a wide variety of evidence (quantitative, qualitative, peer reviewed and grey literature) and have been produced to assist the department to develop appropriate responses to a diverse array of challenges facing those who work in international development in a variety of settings" (DFID, 2011).

Specifically, and in line with general aims described above, this WASH Evidence Paper aims to:

• Provide an accessible guide to existing evidence including a conceptual framework for understanding how WASH impacts on health and well-being and a description of methods used for ascertaining the health, economic and social impacts of WASH

• Present the available evidence on the benefits and cost-effectiveness of interventions on WASH

• Identify what we do know and also what we do not know, and assess the robustness of the available evidence relating to the impact of WASH interventions.

• Disaggregate the benefits, where possible, by gender and poverty and the distribution of the global impacts across regions and economic status of countries.

This WASH Evidence Paper does not make specific recommendations on what DFID should or should not do, but instead identifies key lessons for consideration in evidence-based policy-making in the following areas:

1. evidence of impact
2. evidence of what works
3. evidence on cost-effectiveness and value for money
4. remaining knowledge gaps

1.2. Interpreting the evidence on WASH

DFID has produced various evidence papers spanning a broad range of development sectors and/or interventions, including malaria, unintended pregnancies and cash transfers. Each evidence paper has adopted a tailored approach reflecting the quantity and quality of evidence available but also the prevailing policy and practice questions relating to those interventions or sectors.

WASH brings together multiple interventions – often implemented by different agencies and delivered separately but also together – and is concerned with a wide range of direct outcomes, not just health. For this reason the evidence is complex and does not easily lend itself to a simple or standard classification that might grade evidence as, for example, strong or weak.

In recent years, expectations have risen regarding the quality of evidence required to justify interventions. A consensus has also developed around rules of best practice for the analysis, weighing and combination of such evidence. Central to this culture is the systematic review (Jüni et al. 2001), and the Double-Blind Randomised Controlled Trial (RCT) as the gold standard for quality of evidence. This culture originated in the health sector, but more recently has spread to other sectors and particularly to what is now called behavioural economics (Dawney & Shah 2005).

Below the RCT, there are lesser levels of quality and relevance of evidence to which one may have recourse in the absence of better alternatives. These include unblinded trials, ecological studies, and observational studies, and studies with a related outcome; for example, studies with diarrhoea morbidity rather than mortality as the endpoint. The GRADE approach that uses algorithms for weighing and combining evidence from the different levels has been proposed (Guyatt et al. 2008). One effect of this developing collection of rules (some would argue it is an objective) is to eliminate progressively the arbitrariness of human judgement.

A number of issues specific to the water sector have complicated the application of these rules. First, WASH interventions have multiple outcomes; some have even argued that the non-health outcomes are the most important (Churchill et al. 1987). The principal health outcome of interest is death from diarrhoea, and there are ethical and logistical arguments against studies of that outcome. However, the alternative outcomes, particularly self-reported diarrhoea morbidity, have proved to be more subjective and subject to bias than was originally believed (Schmidt & Cairncross et al. 2009). We shall return to this issue in the following section.

Given the much-appreciated non-health benefits, such as saving time spent collecting water, and the impossibility of providing water and sanitation without the knowledge of the studied population, there are political, ethical and practical reasons why it is difficult to randomise an intervention like water supply and sanitation, or even to allocate it by individual household. For these reasons and because water supplies and sanitation facilities are expensive, researchers were advised not to carry out randomised intervention studies (World Bank 1976) and have rarely done so, but have frequently studied people's health before and after an intervention which was being carried out anyway, on the assumption that the allocation of the intervention (presumably determined by technical and political factors) was effectively random from the health point of view. Many observers dispute that assumption, and on that basis these are sometimes called quasi-experimental studies (Briscoe et al. 1985).

The exposures are also complex. In addition to the three basic dimensions of WASH, there are various levels of service and a variety of combinations of the three. For example, practically every intervention study of sanitation is in fact a study of water and sanitation.

Moreover, the context in which the facilities are provided can vary greatly; a standpipe isolated in the desert is a different level of service from a standpipe in a village where half the households already have household connections. Quite apart from the variation in technology between different settings, there are often important differences in programme design and execution; hygiene promotion implemented effectively in one setting may have been much less effective in another. An epidemiological study in this sector is thus meaningless unless it is seen in the context of the setting in which it was carried out.

If a study is to provide high-quality evidence of health impact, it must be designed to exacting standards of rigour, eliminating the potential for confounding and for bias due to extraneous factors. The more rigorous the study (the more it achieves internal validity), the potentially less relevant it will be to the local context and existing programmes and policy issues; in other words it will lose external validity.

1.3. Review methods

This review is not a systematic review in the conventional sense as the broad aims of this paper do not lend it to this method. However, systematic searches were conducted for all major health outcomes included (apart from diarrhoea) to identify relevant systematic reviews as well as to identify any additional studies not included in those reviews. The search strings and shortlisted studies for these searches are provided in Annexes 1 and 2. For undernutrition, the results of a Cochrane Review which two of the authors for this paper contributed to are used here (Cochrane 2011).

For the effect of WASH on diarrhoea – generally the primary outcome of interest for WASH interventions - there have been a large number of systematic reviews conducted in recent years. We took as our starting point the extensive literature searches recently conducted by some of this paper's authors, the search strategies for which are presented with the published results (Cairncross et al. 2010a; Clasen et al. 2010; Curtis et al. 2011; Fung & Cairncross 2009). This body of evidence was supplemented by studies included in other systematic reviews (Fewtrell et al. 2005a, Waddington et al. 2009). In addition, the collections of the authors as well as the guidance of other experts in the field were used to identify further relevant literature.

Our methods have been heuristic, based on systematic reviews where possible, rather than individual studies. It takes a broader perspective and allows for the range of exposures and outcomes, the variety of settings in which studies have been carried out and the application of judgement based on the joint assessment of the available evidence.

We assessed the evidence for any given impact in terms of the number of viewpoints from which it could be seen, after the manner of Bradford Hill (1965). Bradford Hill's viewpoints are illustrated in Box 1.1 below by examples from the water, sanitation and hygiene literature. In our case, we have developed a pragmatic set of applied viewpoints from which to appraise the evidence base for WASH interventions (see Box 1.2.). Whereas Bradford Hill's viewpoints are for assessing the evidence for causality in an association, ours are to appraise the strength of support for implementation of each intervention.

Box 1.1 Bradford Hill's "Viewpoints" for assessing causality

1. **Consistency** – in a systematic review the impact was similar for the more rigorous studies (Curtis & Cairncross 2003).
2. **Strength of association** – in a study focussed on domestic transmission of a single pathogen, handwashing prevented 85% of secondary cases (Khan 1982).
3. **Temporal sequence** – handwashing by mothers just before preparing the family's food has a greater impact than at other times (Luby *et al.* 2011).
4. **Dose-response** – one study found the impact of a sewer project on diarrhoea in a neighbourhood increased with the proportion of households connected to the sewers (Barreto *et al.* 2007).
5. **Specificity** – water treatment affects diarrhoea, but not malaria.
6. **Coherence** (i.e. laboratory & epidemiology results cohere) – e.g. more faecal bacteria in drinking water are associated with more frequent diarrhoea (Moe *et al.* 1991).
7. **Biological plausibility** – given the number of fecal pathogens present in a community's waste, it is not surprising that excreta disposal helps to prevent excreta-related disease (Feachem *et al.* 1983).
8. **Analogy** – in particular, sanitation helps to prevent intestinal worm infections; it can therefore be expected to prevent transmission of other fecal pathogens, such as those causing diarrhoea.
9. **Experimental evidence** – this refers to intervention studies, ideally randomised trials, many of which have been carried out for household water treatment.

Box 1.2. A set of viewpoints proposed for appraising the evidence base for WASH interventions

1. **Internal validity** – rigour of the studies in demonstrating cause and effect, including randomisation, blinding (or use of objective outcome) etc.
2. **External validity** – relevance to programme conditions in the field
3. **Ease of going to scale** – without dilution of impact
4. **Sustainability of the intervention** – assuming reasonable effort is devoted to maintaining it
5. **Other substantial health benefits** – in addition to impact on diarrhoea
6. **Significant non-health benefits** – such as time-saving or security
7. **Cost** – not strictly a viewpoint, but a factor to bear in mind

Table 1.1 shows the degree to which, from each viewpoint (Box 1.2), the available evidence supports or undermines the case for implementation of each type of intervention. The grading given for each cell of the table also reflects the gradings given for the strength of evidence throughout this paper. Thus, subject to all the caveats and provisos mentioned above, the table summarises the variation in the strength of the evidence base of the sector. This kind of exercise necessarily involves some necessary simplification. For example, the internal validity rating for hygiene promotion relates to a single study (Khan 1982); and the ratings for water quality represent a compromise between household water treatment and water supply construction.

Table 1.1 Assessment of the evidence underlying the impact of the four main WASH interventions on diarrhoea from the seven points of view in Box 1.2

Note:

+++ favourable

++ intermediate

+ unfavourable

	Internal validity	External validity	Sustain-ability	Other health benefits	Non-health benefits	Low cost
Water quality	+	+++	++	++	+	++
Water availability	++	+++	+++	+++	+++	+
Excreta disposal	+	++	+++	+++	+++	++
Hygiene promotion	+++	+	+	+++	+	+++

When a recent systematic review on point of use (POU) water treatment was published in the British Medical Journal (Clasen et al. 2007), it was clear from the nearly 40 RCTs reviewed, many of them conducted by well-known specialists from the US Centres for Disease Control, that drinking water quality improvements were associated with reductions of nearly 50% in diarrhoea rates. As a result, a number of international agencies increased the level of priority and investment for POU interventions. However, there was subsequently some anguish when it became clear that the three or four blinded studies showed no impact at all on diarrhoea, raising the possibility that the impact previously noted was the result of placebo effect or courtesy bias – in which case it would be much smaller than assumed (Schmidt & Cairncross 2009). The evidence base, previously deemed very strong, may now only be judged “suggestive”.

This newly-identified weakness in the evidence base is not restricted to water quality interventions. The other WASH interventions all involve behaviour change and so by their nature, their allocation usually cannot be blinded. The problem thus applies to all studies of those other interventions in which self-reported diarrhoea is the outcome measure. Moreover, the assessments in Table 1.1 are based on the assumption that each intervention is implemented correctly, thoroughly and permanently; in other words, they relate to efficacy. Effectiveness relates to the implementation conditions of real programmes at full scale. For hygiene behaviour change in particular, concerns have been raised about a dilution of impact with increasing scale, which can be seen as a divergence between efficacy and effectiveness (Curtis et al. 2011).

The sustainability of hygiene behaviour change is also open to question; there are very few studies of it, with debatable results (Vindigni et al. 2011). One review found only five studies, of which three used self-reported handwashing as an outcome, although it has long been known that self-reporting is not a valid measure of handwashing practice. The two studies using more objective outcomes (such as purchases of soap) obtained contradictory results (Luby et al. 2009).

However, while the evidence in many domains may be weak, it is nonetheless voluminous; this means that while it may be questioned and undermined to a greater or lesser degree, it is unlikely to be negated quickly. Therefore, even if we are uncertain about the strength of the particular impact and the circumstances in which it is strongest, this uncertainty does not mean there is no impact nor that the intervention is not worth making.

For this Evidence Review, we have been asked to show which relationships are supported by firm evidence and which by relatively weak evidence; a similar approach was taken recently for the different aspects of hygiene behaviour (Curtis et al. 2011). However that paper stated only the *type* of evidence and avoided statements about its *strength*. Throughout this paper, we consider the type of evidence but also seek to grade the strength of the evidence according to the following three categories:

• **Good evidence**: several good quality studies consistently show an effect. E.g. randomised trials with a low risk of bias; observational studies showing a large effect size with a low potential for confounding.

• **Suggestive evidence**: studies show an effect but statistical support is weak due to insufficient study size. Or studies show significant effects but there is a risk of bias and confounding.

• **Weak evidence**: no studies have been done or, where they been done, they have shown inconclusive results.

2. Progress on WASH

The Millennium Development Goal (MDG) target for water and sanitation provides a useful framework to monitor global, regional and national progress in extending access to safe water and sanitation. Using data collected by national statistics offices and other relevant institutions through household surveys and censuses, the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) estimates progress against the MDG target. Over 600 surveys and censuses are used, including the USAID Demographic and Health Surveys (DHS) and the UNICEF Multiple Indicator Cluster Surveys (MICS).

The JMP estimates for coverage are used here as the best source of comparable data from across countries and regions. The JMP acknowledges that, “indicator definitions and population estimates used by the JMP sometimes differ from those used by national governments. Coverage estimates in this report may therefore differ from national estimates” (WHO/UNICEF JMP, 2010).

Since 2008, the JMP has introduced water supply and sanitation ladders to classify service improvements. These allow disaggregated analyses of trends for access to water supply and sanitation. Figure 2.4 shows both ladders and what they include.

The water ladder has three “rungs”:
1. Unimproved,
2. Other improved
3. Piped water.

The sanitation ladder has four “rungs”:
1. Open defecation
2. Unimproved
3. Shared
4. Improved.

There is no comparable set of data to obtain estimates for the practice of hygiene behaviours globally, or indeed regionally or nationally. Reliable data for the prevalence of hygienic behaviour is particularly problematic. The findings of one of the more comprehensive studies conducted across multiple low-income settings to estimate prevalence of the handwashing with soap practice at critical times among household child-carers in eleven developing countries (Curtis *et al*. 2009) are given in Table 2.1 below. On average, only 17% of those surveyed washed their hands with soap after defecation with an even smaller proportion doing so before handling food (13%) and after before feeding a child (5%).

Table 2.1 Handwashing with soap and water by mother or caregiver on key occasions

Table III. *HWWS and water by mother or caregiver on key occasions*

Country	*n*	HWWS after toilet (%)	HWWS after cleaning child (%)	HWWS after cleaning up child stools (%)	HWWS before feeding index child (%)	HWWS before handling food (%)	HW with water only after toilet (%)
Ghana	500	3	2	—	1	—	39
Kerala, India	350	42	—	25	—	—	—
Madagascar	40	4	—	—	12	—	10
Kyrgyzstan	65	18	0	—	—	—	49
Senegal	450	23	18	—	—	18	—
Peru	500	14	—	—	6	—	—
Sichuan, China	78	13	—	16	6	—	87
Shaanxi, China	64	12	—	—	16	—	14
Tanzania	30	13	13[a]	13[a]	4	—	33
Uganda	500	14	19	11	6	8	44
Vietnam	720	—	14	23	5	—	51
Kenya[b]	802	29	35	38	13	15	57
Average		17	13	19	5	13	45

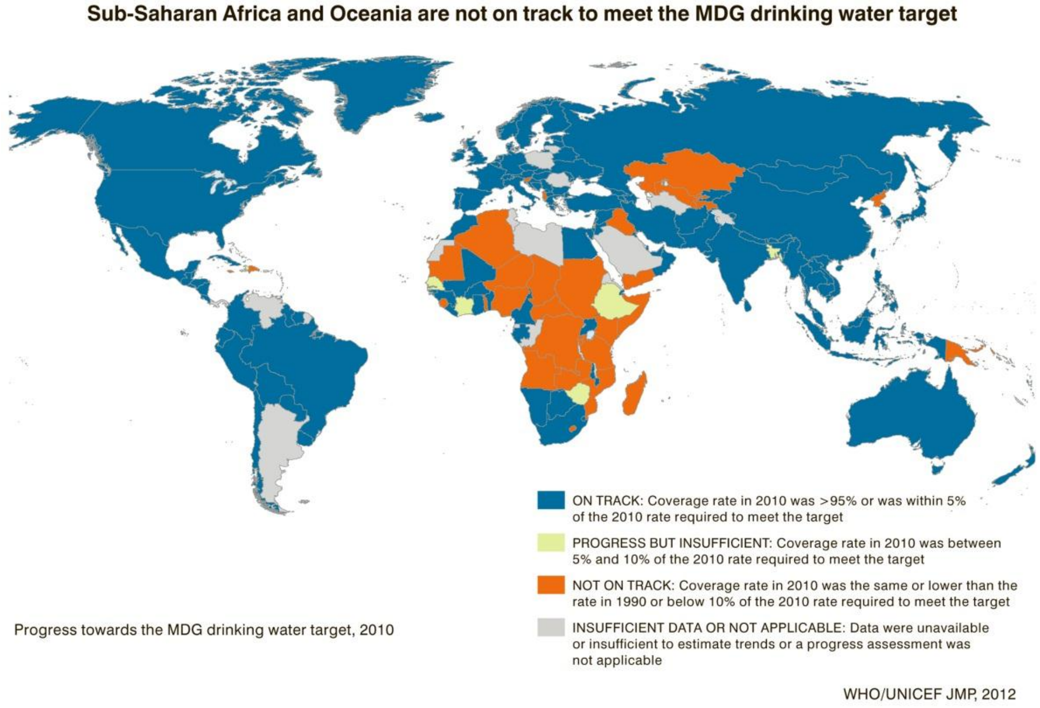
'—' means not reported.
[a]Tanzania: the figures quoted are the same as the observation was based on whether the person assisting the index child washed their hands after wiping a child's bottom or cleaning child's faeces.
[b]Kenya: note high figures for HWWS are thought to be a temporary response to a cholera epidemic and a current government handwash campaign and hence have not been used in the calculation of averages.

Source: Curtis *et al*. 2009

2.1 Global progress on improving access to safe water and sanitation

The MDG Target 7c for water and sanitation aims to halve the proportion of people without sustainable access to safe water supply and basic sanitation by the year 2015. In their most recent report, the JMP estimates that 2.5 billion people are still without access to improved sanitation and 780 million people are without access to an improved water supply (WHO/UNICEF JMP 2010). In relation to the MDG 7c, it was announced in 2012 that the target for water has been met but the target for sanitation remains one of the most off-track of the MDG targets. Although the water target has been met, 780 million people remain un-served. It has also been argued that many of those water sources classified as 'improved' do not provide water of adequate microbial quality (Bain *et al*. 2012). Finally, Bartram and colleagues argue that the influence of increases in the number of households, as distinct from population growth, has not been adequately accounted for and may have led to over-estimates of coverage (Bartram *et al*. 2012).

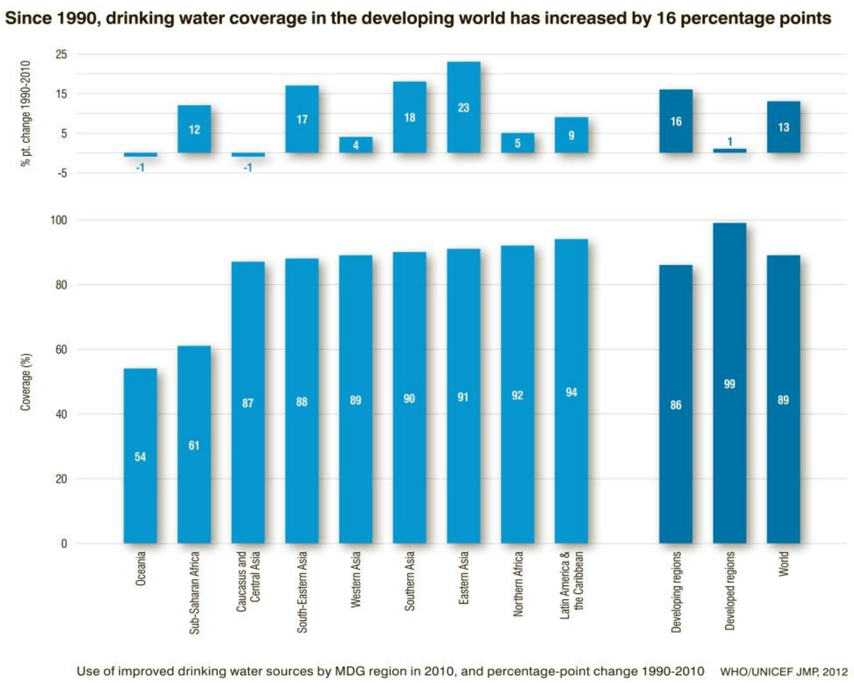
Figure 2.1 Global progress towards the MDG target for sanitation



Source: WHO/UNICEF JMP 2012

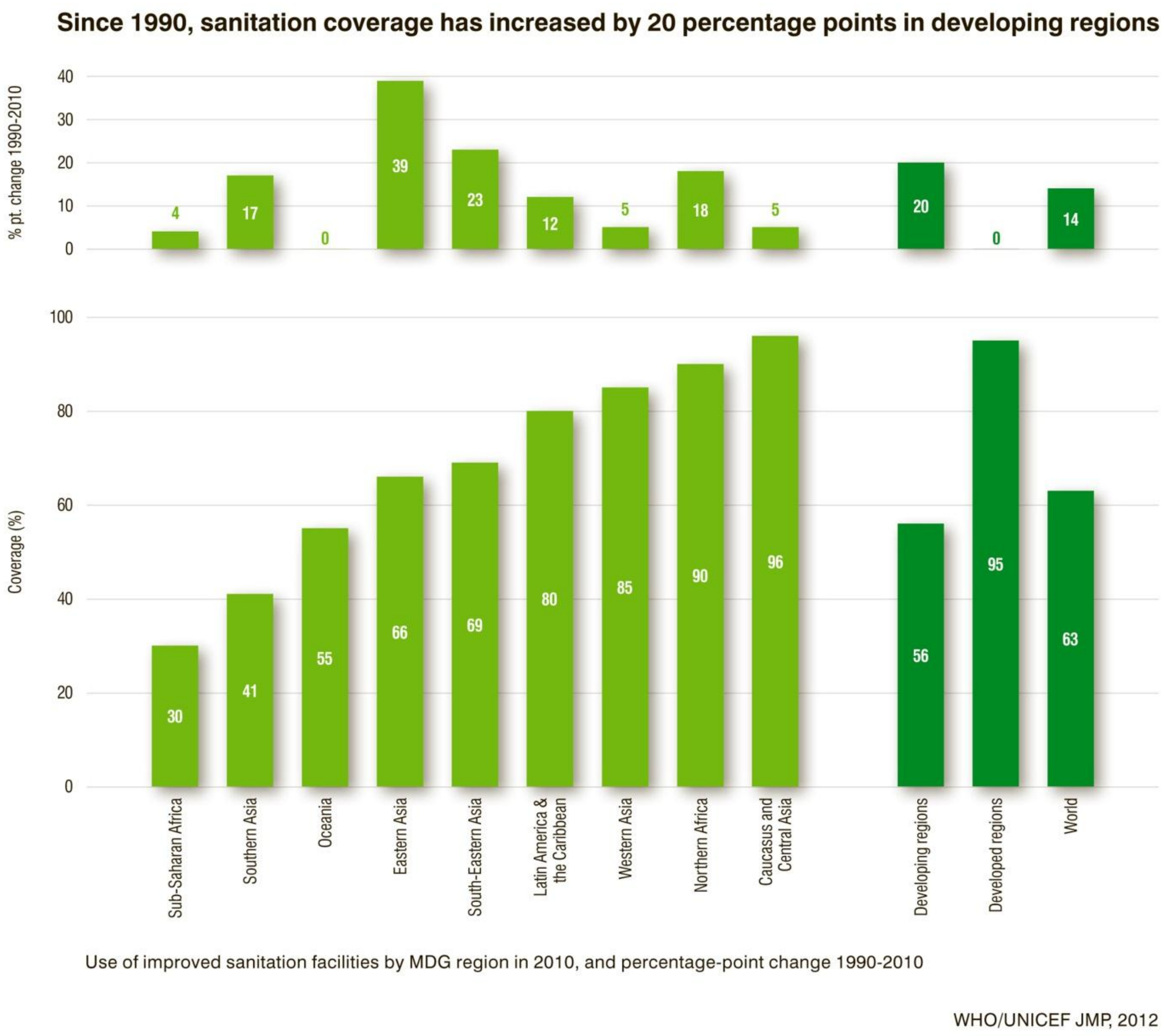
Figure 2.2 below shows the proportional trends in global coverage for drinking water supply and sanitation. The proportion of the world population with access to improved water supply has increased from 77% in 1990 to 89% in 2010. For sanitation, figure 2.3 shows that access to improved sanitation has increased at a lesser rate than that for water supply, from 54% in 1990 to 63% in 2010.

Figure 2.2 Use of improved drinking water sources by MDG region in 2010 and percentage-point change 1990-2010



Source: WHO/UNICEF JMP 2012

Figure 2.3 Use of improved sanitation facilities by MDG region in 2010 and percentage-point change 1990-2010



Source: WHO/UNICEF JMP 2012

Global progress on the MDG targets for water and sanitation is largely determined by the rate of progress in the most populous countries of the developing world. For water, 5 out of 10 of those gaining access to improved water since 1990 live in India or China and, for sanitation, 4 out of 10 gaining access have been in those two countries.

2.2 Regional progress on improving access to safe water and sanitation

Access varies greatly between, and within, regions, and global rates of progress often mask significant variance in rates of progress in, and between, regions.

The proportional nature of the MDG target can result in many countries with some of the most rapid gains in coverage being identified as “off-track.” For example, Yemen, Benin, Cameroon and Mali have all increased sanitation coverage by 30% or more since 1990 but are still categorised as “off-track” due to the low level of coverage at baseline.

The proportion of people with access to improved water and sanitation facilities has increased in all developing regions since 1990, but the rate of progress varies significantly for both water and sanitation (WHO/UNICEF JMP 2012).

Water

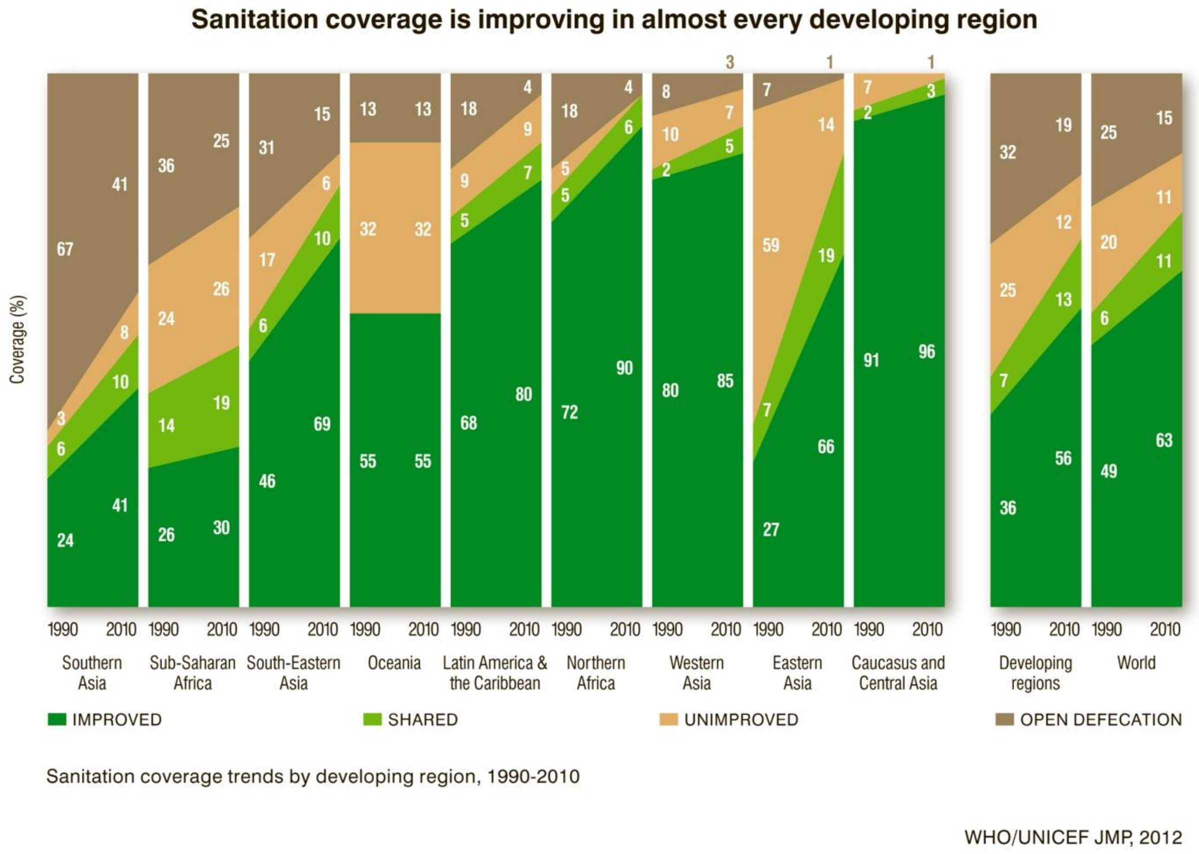
Whilst globally the water MDG target has been met, large disparities exist between regions and countries as shown in Figure 2.2. Whilst 89% of the global population have access to an improved water source, in sub-Saharan Africa, only 61% have access. In sub-Saharan Africa 39% of the region’s population are without access to an improved source. In South Asia and South-East Asia the proportions without access to safe drinking water are 10% and 12% respectively, although almost all countries in these regions are considered on-track to meet the MDG target and have made significant progress since 1990.

When further categories of access or service are considered, these disparities increase. In most regions, the greatest rate of increase in access has been for household connections (water piped on premises), a level of access that is greater than that required for the JMP definition of ‘an improved source’. For developing countries though, progress on household connections remains weak with coverage for piped water on premises increasing by only 5% in South Asia and 1% in sub-Saharan Africa in the two decades since 1990. The vast majority of the population in both of these two regions rely on shared sources whether these are improved or unimproved. The implications of this in terms of health and other benefits are discussed below.

Sanitation

Although 1.8 billion people have gained access to improved sanitation since 1990, the MDG target for sanitation is described as “seriously off-track.” Much of the deficit is in sub-Saharan Africa and South Asia where most countries are off-track as shown in Figure 2.3. Figure 2.4 shows trends for all regions for all “rungs” of the sanitation ladder.

Figure 2.4 Sanitation ladder: global and regional trends



Source: WHO/UNICEF JMP 2012

Sub-Saharan Africa and South Asia have the lowest levels of access to improved sanitation at 30% and 41%. Notably, 1.1 billion people in the world still practice open defecation. Regionally, the highest levels of open defecation are found in South Asia (41%) and sub-Saharan Africa (25%). Over half of all people practising open defecation globally live in India.

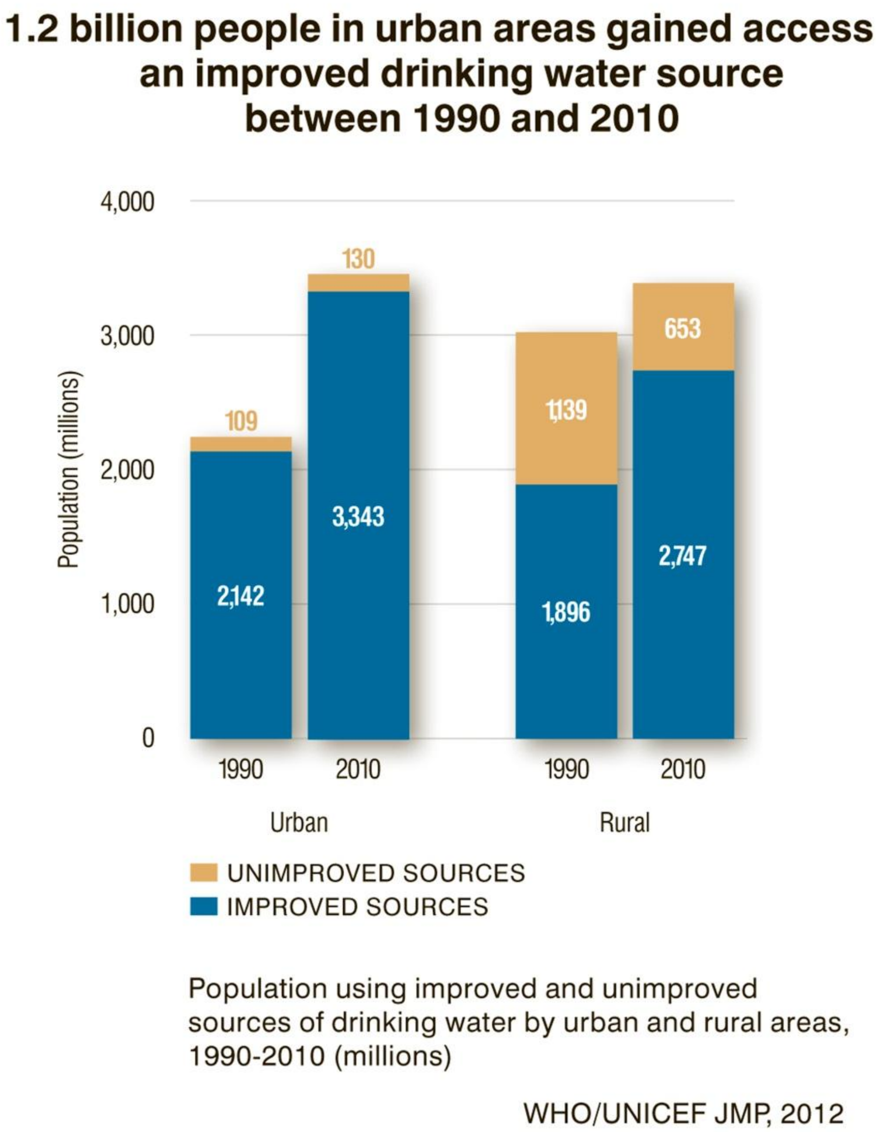
2.3 Disparities in access to WASH

Urban and rural settings

There are marked disparities in access to safe water and sanitation between urban and rural populations.

The rural population without access to an improved drinking water source is over five times greater than that of the urban population without services (figure 2.5). This disparity is most marked in sub-Saharan Africa, but is also prominent in South Asia and Latin America. However, whilst progress on increasing access to water and sanitation struggles to keep pace with urban population growth, by contrast access to water and sanitation is increasing beyond the rate of rural population growth in most regions (WHO/UNICEF 2010).

Figure 2.5 Drinking water trends by urban and rural between 1990-2010



Source: WHO/UNICEF JMP 2012

Whilst levels of access may be higher in urban areas, high faecal contamination of the environment poses a greater theoretical risk in high density areas. Lack of space causes other complications such as the cost and design of water and sanitation technologies, and in many urban settings land tenure can prevent tenants from making sanitation improvements.

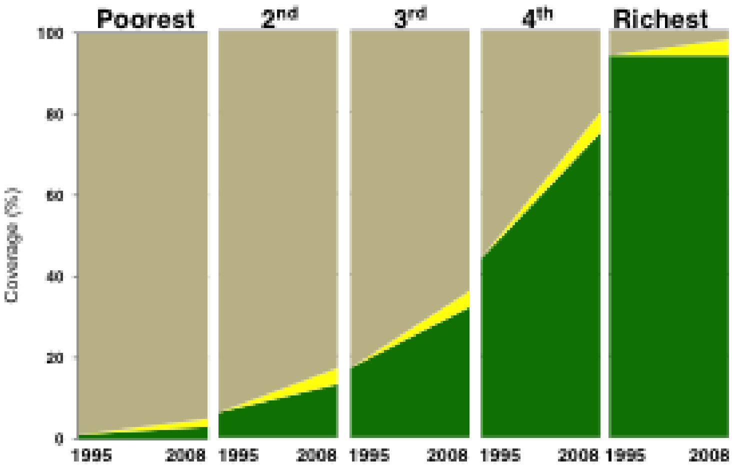
Progress by wealth quintiles

Recent work by UNICEF (UNICEF 2010; WHO/UNICEF 2011) using Demographic Health Surveys (DHS) and Multiple Indicator Cluster Surverys (MICS) data has considered the differentiated rates of progress for water and sanitation across national wealth quintiles. The work contains various disclaimers and acknowledges certain methodological weaknesses, but provides useful insights.

Figure 2.6 shows the trends for sanitation access between 1995 and 2008 for India and Bangladesh.

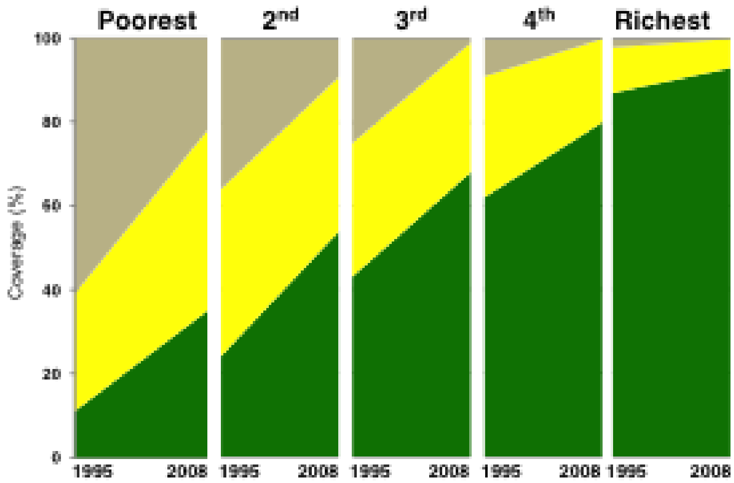
Figure 2.6 Sanitation trends by wealth quintile for India and Bangladesh

India



Source: WHO/UNICEF JMP 2011

Bangladesh



Source: WHO/UNICEF JMP 2011

Whilst significant gains have been made in India, with 166 million people gaining access to improved sanitation between 1995 and 2008, only 3% of that increase occurred among the poorest 20% of the population and almost half of this increase was among the richest 20%. By contrast in Bangladesh, the poorest 20% captured 16% of the gains made and the richest only 23% (WHO/UNICEF 2011).

Ensuring that progress is equitable remains a major challenge for the sector. These inequities extend beyond household wealth to the rural/urban divide and to issues of social exclusion such as gender, age, and disabilities. The data presented by UNICEF and WHO is an important step in highlighting the disparities in access and progress, but more research is needed to understand the causes and impacts of these disparities.

The challenge of sustaining access to WASH

Increasing attention, if not yet priority, is being given to the issue of the sustainability of services. Beyond increasing access to services, it is vital that existing services are maintained. This has significant implications both in the design and delivery of services, but also the investment needs over time (Hutton & Bartram 2008; Fonseca *et al.* 2011).

Sustainability is about whether or not WASH services continue to function and whether good hygiene behaviours are practised over time and continue to deliver benefits. In other words, sustainability is about permanent beneficial change in WASH services and hygiene practices as described by one international Non-governmental organisation (NGO) active in the WASH sector (WaterAid 2011).

There is extensive observational evidence that newly delivered WASH services often perform effectively for a period, and then either fall into disrepair or otherwise fail to provide continuing benefits to their users. Poor maintenance can affect water quality – for instance changes in pressure draw in contaminants through fractures in pipes. A lack of maintenance of hand pumps in rural areas may lead to people using alternative and less protected sources. One study estimates that a third of handpumps in Africa are non-functional (Reed & Harvey 2004). There is some evidence that raising the standard of water supply services and then letting even occasional short-term failures in water supply or water treatment occur can very quickly [in a matter of days] reverse many of the hard won public health benefits (Hunter *et al.* 2009). If communities slip back into a situation where they have to rely on unimproved water and sanitation services then investment has effectively been wasted.

Figure 2.7 shows time-series data of rural water supply functionality data from six districts of Tanzania collected and analysed as part of a WaterAid research study carried out in 2006.

Figure 2.7 Functionality of rural water supply schemes by age, Tanzania

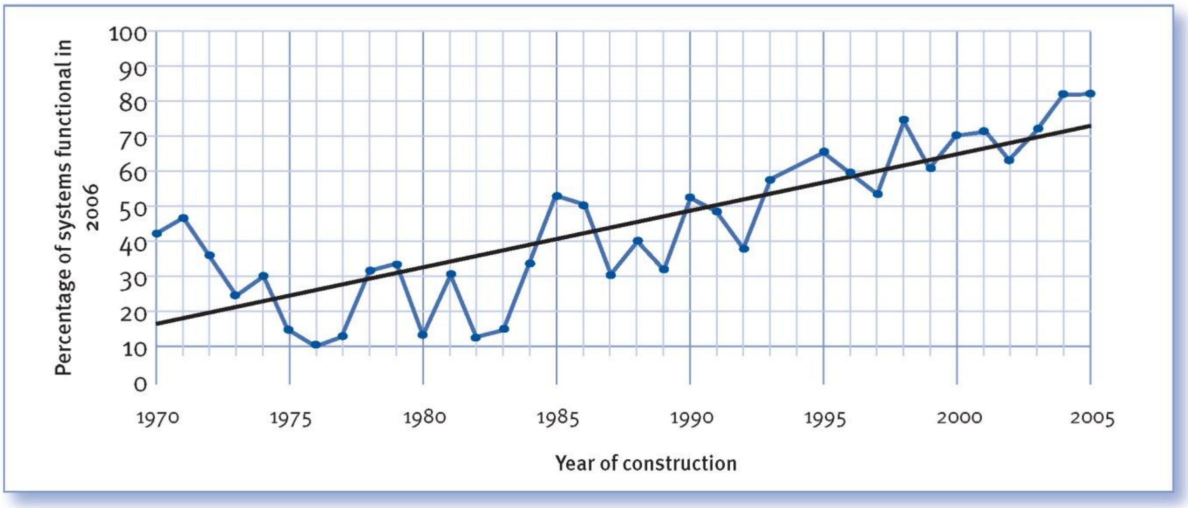


Figure 1 Functionality of rural water supply schemes by age (six districts of Tanzania)

Source: WaterAid 2011

Sustainability seems to be a problem not only with public water supply systems, but also with household water treatment. A meta-regression analysis by Hunter (2009) adjusted for the lack of blinding using a coefficient derived by Wood *et al.* (2008) from clinical studies of various conditions. It found that the effect of all the treatment technologies declined with time, becoming insignificant after six months of follow-up for all except ceramic filters. Some analysts might question the use of a factor derived from clinical studies to analyse trials in the community. Others might note that many of the trials of ceramic filters used an innovative diarrhoea measurement methodology (Schmidt *et al.* 2010b) requiring fewer home visits at longer time intervals. In such conditions, it would not be surprising for any courtesy bias to last longer, until the visits became routine. Nevertheless, this analysis is important for questioning the sustainability of this as for other WASH interventions.

Environmental sustainability is a further issue of importance for water supplies, ensuring that the available water resources can meet all the needs placed upon it and thus provide water security (Grey and Sadoff 2007), and that pollution is managed. Hunter *et al*. (2010) cite studies showing inadequate water resource availability has led to loss of water supply in Africa. Foster & Chilton (2003) note the specific problems related to groundwater use and the risks of over-abstraction combined with emerging threats from urbanisation and climate change as presenting serious challenges for the sustainability of groundwater-based water supplies. UNEP in their post-conflict environment assessment of Sudan's (2007) noted that water supplies for camps solely relying on the basement complex were probably unsustainable in medium-term. Howard *et al.* 2010 note that longer-term water supplies, as well as sanitation services, face significant technological and management challenges from climate change.

Pit latrines have a host of well-recognised and common shortcomings, often over-looked by both researchers and programming organisations. One of the most problematic faults, particularly in high density urban areas, is that all pits, no matter what their initial volume, will eventually fill and must be emptied or replaced. This is a major disincentive to pit construction and latrine improvement. Pit lifetime is likely to depend on a variety of factors, the most important of which are the number of users, the size of the pit, the degree to which the pit or tank is drained, and the degree to which the pit is used for disposal of other household waste, varying from as few as three to as much as twenty years. A family unable to meet such a cost has little other option than to either return to open defecation or employ a local manual pit emptier to climb into the pit and remove the waste with buckets. There may also be significant public health implications associated with unregulated manual pit emptying although these have not quantified.

Box 2.1. What happens when the pit fills up?

Slowing the rate at which pit latrines fill would derive significant benefits in terms of extended use and lower costs. If an additive could slow pit filling by 50% this would effectively halve the annual household cost of latrine provision and allow other expenditure to be prioritised e.g. school fees, health care cost. This question is currently being investigated by a team at the London School of Hygiene and Tropical Medicine through a three-year grant provided by the Bill and Melinda Gates Foundation.

Sustainability issues are further discussed in section 8 below.

3. How WASH impacts health and well-being

The following section considers evidence on how improved WASH impacts on health and well-being, and presents a conceptual framework that models the relative risk of diarrhoea – the most common outcome of interest in WASH health studies – associated with different interventions. It goes on to explain the role of WASH in the prevention of the transmission of disease, and the challenges associated with supporting the evidence base. Finally, current levels of progress in extending WASH coverage globally and regionally are analysed.

3.1 Towards a conceptual framework

This section concludes with two similar conceptual models for the impact of WASH on diarrhoea. Whilst the conceptual framework is useful, the model necessarily limits the outcome of interest to diarrhoea alone. This model, therefore, excludes both the non-health impacts of WASH and indeed the other health impacts associated with WASH that are discussed in section 4. The non-health impacts and may often been more important in motivating factors for households and community investments and uptake in WASH services. The range of non-health impacts of WASH are discussed in section 7.

3.2 The evidence base for a conceptual framework

The ways in which water supply, sanitation and hygiene affect health are complex. 'WASH' includes a number of interventions which interact, and may or may not be combined; each of them can be provided to various levels of service impacting disease transmission in several different ways and affecting a wide range of diseases, not to mention the social impacts described in the previous section. All this makes the rigorous study of health impacts more complicated.

Moreover, water supply and sanitation do not lend themselves to randomised trials as easily as interventions against other diseases. Water supply improvements generally apply to a community as a whole, which makes the community necessarily the unit of randomisation. Sanitation can be applied at the household level but is expensive if the trial is to fund it. Either way, randomised trials of water supply and sanitation have been rare because of their cost.

The evidence for the health benefits of WASH has, therefore, largely come from observational studies, in which the health of a group of people who are underserved is compared with the health of a group of people who are served. The problem is that these two groups are not comparable to begin with. There is evidence from Bangladesh (Hoque *et al.* 1995) and from Brazil (Strina *et al.* 2003) that people who have toilets practice better hygiene, so that one cannot tell whether it is their toilet which protects their health, or the factors which predisposed them to install a toilet. A study might find that owners of televisions or air fresheners enjoyed better health, but that would not prove that televisions and air fresheners *provide* better health.

In an effort to avoid the taint of confounding associated with observational studies, some reviewers of the literature have considered before and after studies as “quasi-randomised intervention studies.” However, as long as the intervention is allocated on technical or political criteria, the risk of confounding remains.

In the circumstances, it is hardly surprising that when Blum and Feachem (1983) conducted a review of about 50 health impact studies from water and sanitation, they found that every one of them had at least one obvious methodological shortcoming. This makes interpretation of the literature a matter of judgement; which shortcomings can be admitted without introducing erroneous conclusions? Judgement-free data are rare indeed.

Further, it has recently become clear that the outcome of interest in most health impact studies – self-reported episodes of diarrhoea in young children – are not immune to bias. This is illustrated by the way in which some 30 randomised trials appeared to show reductions of nearly 50% in diarrhoea rates, until a small number of blinded trials failed to show such reductions (Schmidt & Cairncross 2009).

Of course, studies of some other WASH interventions cannot be blinded; for example, it is hard to imagine how a study might allow for persuading subjects to wash their hands without their knowledge. To avoid this problem of bias, it will be necessary to: (1) use hard outcomes (such as laboratory-confirmed infection with a specific pathogen, or nutritional status), or else (2) apply the blinding to some other aspect of the study design (for instance, blind the data collection workers to the study hypothesis).

Fortunately, there are a number of studies using hard outcomes in the field of hygiene promotion, with examples given in Table 3.1. The first two are intervention trials.

Table 3.1 Hygiene promotion studies, outcome and ascertainment

Reference	**Outcome and its ascertainment**
Khan 1982	Rectal swabs from all subjects
Han & Hlaing 1989	Two independent field workers, each blinded to household’s allocation status
Velema *et al.* 1997	Clinically diagnosed typhoid fever, 90% confirmed by Widal.
St Louis *et al.* 1990	Hospitalised cases of cholera
Khin *et al.* 1994	Hospitalised cases of diarrhoea with kwashiorkor

Source: Cairncross & Curtis 2003

Some studies in the water and sanitation literature also use hard outcomes. However, in water supply, sanitation and also in hygiene promotion, most of those are not intervention studies, and so are susceptible, at least in principle, to confounding.

On the other hand, the literature on the health impacts of WASH interventions has one strength by comparison with studies of other diseases such as malaria. The difference between studies of efficacy (in which highly motivated researchers with adequate resources work with small numbers of subjects) and effectiveness (in which interventions are implemented at scale through the normal agencies), which bedevils much of the public health literature, is much less important for WASH. Since WASH interventions often can only be carried out at scale, health impact studies are more often studies of effectiveness than of efficacy. This increases their external validity (Table 1.1).

3.3 A conceptual model for WASH and diarrhoea

As mentioned above, the health benefits of WASH are various and complex. To simplify matters, much of this document focuses on diarrhoeal disease, which represents about 90% of the avoidable disease burden prevented by good water supply, as has been shown with mortality figures by White, Bradley and White (1972) and with DALYs by Rosen and Vincent (2001). The high contribution from diarrhoeal diseases is mainly due to the deaths which they cause. The majority of these deaths are of children under five years old; indeed most of them are of children aged less than two (Cairncross & Valdmanis 2006).

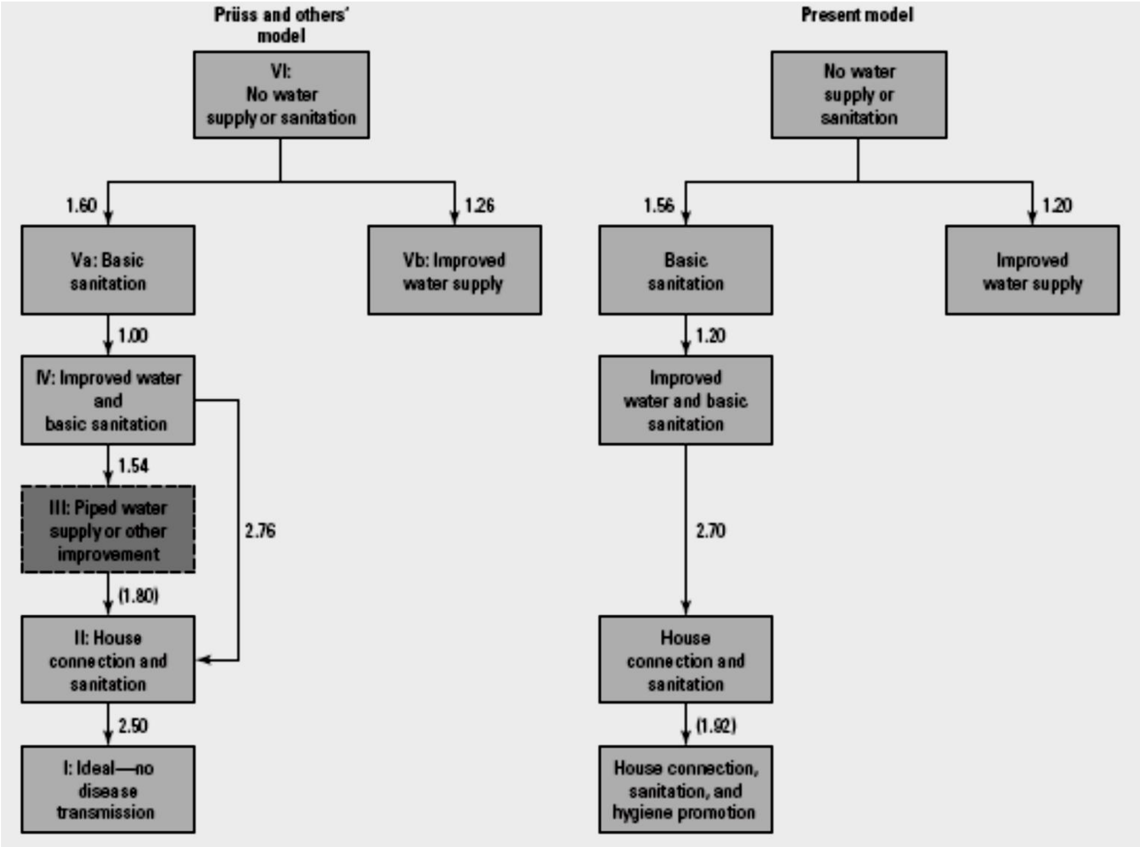
A further simplification is provided by the assumption that an intervention which reduces diarrhoeal morbidity by a certain percent will reduce diarrhoeal mortality by the same proportion[1]. A few studies with diarrhoeal mortality as an outcome (Victora *et al.* 1988), presented later in this review, provide some underpinning for this. Finally, water supply was separated into its quality and quantity components and collapsed into two levels of service; "improved" and "house connections". Sanitation also was reduced to a single intervention, and promotion of handwashing with soap was taken to represent hygiene promotion in general.

On this basis, the "present model" shown below (Figure 3.1) was constructed by Cairncross & Valdmanis (2006). This shows the strength of association between each intervention and the corresponding reductions in diarrhoeal disease. Note that the strength of association is not the same as the strength of the evidence, which has been discussed above. Due to the uncertain quality of much of the underlying evidence, this diagram (as with other findings) is the subject of debate. Another model was developed by Prüss and colleagues (2002) for the global burden of disease study and is shown below as "Prüss and others' model" alongside that of Cairncross & Valdmanis (figure 3.1). Although starting from different premises, the two conceptual frameworks lead to very similar conclusions regarding the burden of disease preventable by WASH.

[1] The relationship is not two-way; interventions to reduce mortality (such as ORT) do not reduce morbidity.

Figure 3.1 Conceptual model of impacts of WASH interventions on diarrhoeal diseases

Note: the numbers show relative risk of diarrhoea in higher relative to lower boxes. Relative risks in parentheses are set to 1.0 for the minimal version of the Prüss model and for the realistic version of the present model



Source: Cairncross & Valdmanis 2006

3.4 WASH and disease transmission

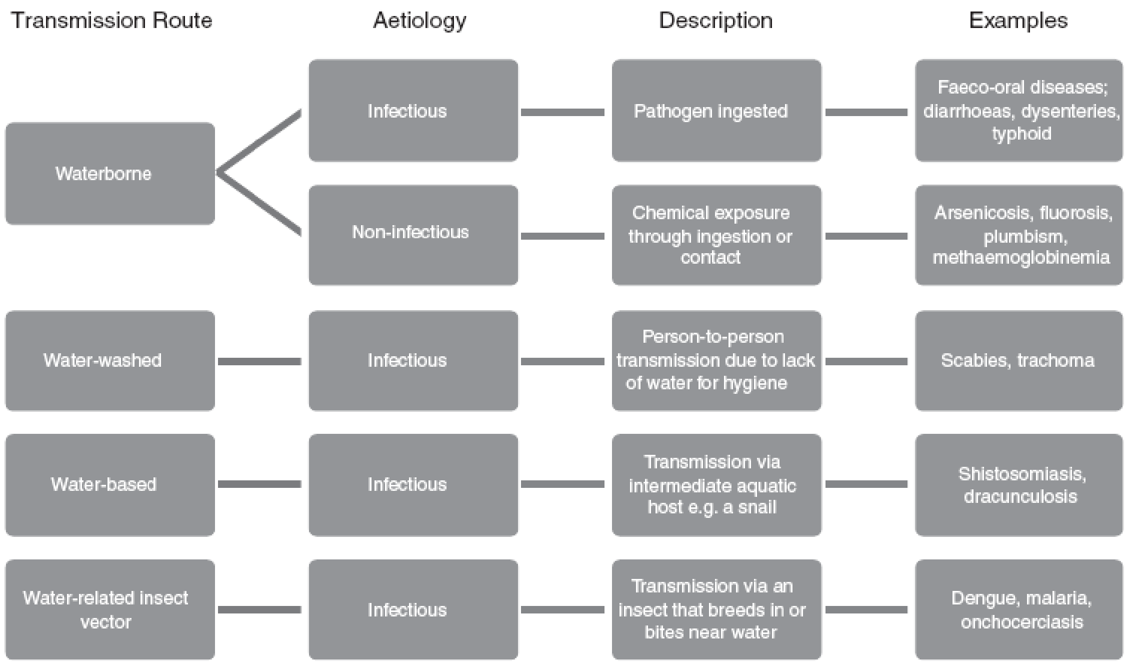
The transmission routes of different excreta and water-related diseases are closely linked and are best imagined as a web of pathways influencing each other. For example, a person sick with diarrhoea can infect another person by direct contact, or by contaminating food, the environment or water. Flies can act as vectors of pathogens effectively connecting the different pathways.

As a consequence WASH interventions are likely to be closely linked as well, although it may be difficult to demonstrate this in practice. Improved access to water facilitates hygiene (Biran *et al*. 2008, Schmidt *et al.* 2011) Good hygiene can prevent recontamination after collecting water from the source. Water access greatly facilitates use of sanitation. For example, use of pour-flush latrines clearly depends on the availability of water. Only if water is readily available will people use such latrines in the long-term. At the same time, inadequate sanitation may threaten the quality of nearby water sources. Inadequate sanitation increases fly numbers (Emerson *et al.* 2004), which can make maintaining food hygiene very difficult.

Lack of water can also lead indirectly to disease via malnutrition. Several authors argue strongly for investments in low-cost water harvesting techniques, irrigation, and clean water provision as a means of increasing food production, improving food security and reducing infectious disease burden (Hunter *et al.* 2010).

Despite this complexity, it is useful to classify infectious water and excreta-related diseases according to their main mode of transmission to illustrate the importance of different WASH interventions. Figure 3.2 below shows a modified Bradley classification, that classifies water and excreta-related diseases not by pathogens, but by the main transmission pathways.

Figure 3.2 Adapted Bradley classification of water-related illness



Source: Dar & Khan 2011

Some pathogens are predominantly "water-borne" (transmitted by contaminated water), especially cholera and typhoid fever. Many pathogens causing diarrhoea and respiratory infections are transmitted by person-to-person contact and contaminated hands. These germs can be controlled by water and hygiene and are thus called "water-washed" infections. Apart from these two generic transmission routes, some pathogens use complex vector-host relationships for multiplying and transmission, that are either water-based (e.g. schistosomiasis) or rely on insects that breed in water.

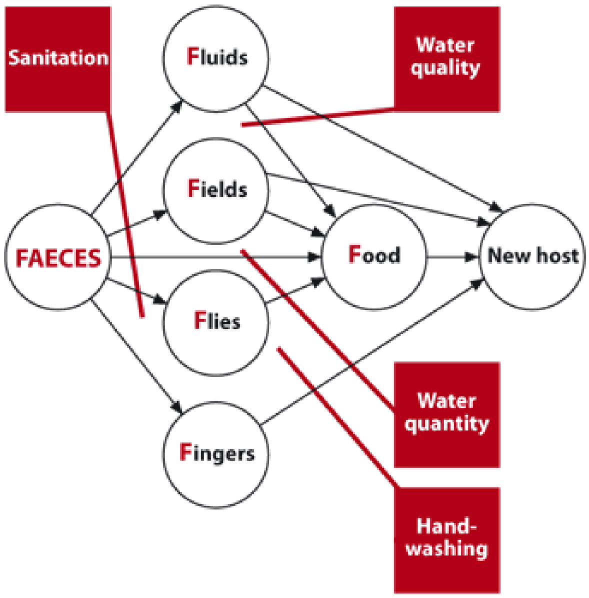
Beyond the addition of "non-infectious water-borne" illness shown in Figure 3.2 (and discussed in section 4. below), others have critiqued this classification for not taking account of other causal pathways such as those health effects associated with collection and transportation of water, such as the impacts on musculo-skeletal health of carrying water (Hunter *et al.* 2010).

Whilst this classification suggests that the transmission of a particular pathogen is confined to a single pathway, in reality many travel by multiple pathways. Whatever transmission pathway predominates for a particular excreta and/or water-related disease, there is little doubt that inadequate disposal of human faeces is a major factor for the transmission of disease. This is highlighted in the classic ‘’F Diagram’’ below which also points to key features of the transmission chain as potential targets for different WASH interventions.

The F-diagram (figure 3.3) graphically presents the importance of good sanitation in safely removing faeces from human contact. Hygiene then acts as a secondary barrier through handwashing after defecation or handling children’s faeces and before storing and preparing food and water. The diagram is also important as it shows the existence of multiple transmission routes for multiple faecal pathogens.

The three critical methods of guarding against transmission of excreta- and water- related pathogens are: water (both quantity and quality), sanitation and hygiene (WASH).

Figure 3.3 “F-diagram”: Routes of faecal-oral disease transmission and protective barriers



The F-diagram, first developed by Wagner and Lanoix in 1959, illustrates the major transmission pathways for excreta-related pathogens. The model depicts the five intermediary transmission environments from which an individual may become infected with a faeco-oral pathogen: fluids, fields, flies, fingers, and foods. Pathogens may travel via unwashed hands, in contaminated water, or by flies and other insects on to further human hosts.

Source: Wagner & Lanoix 1959

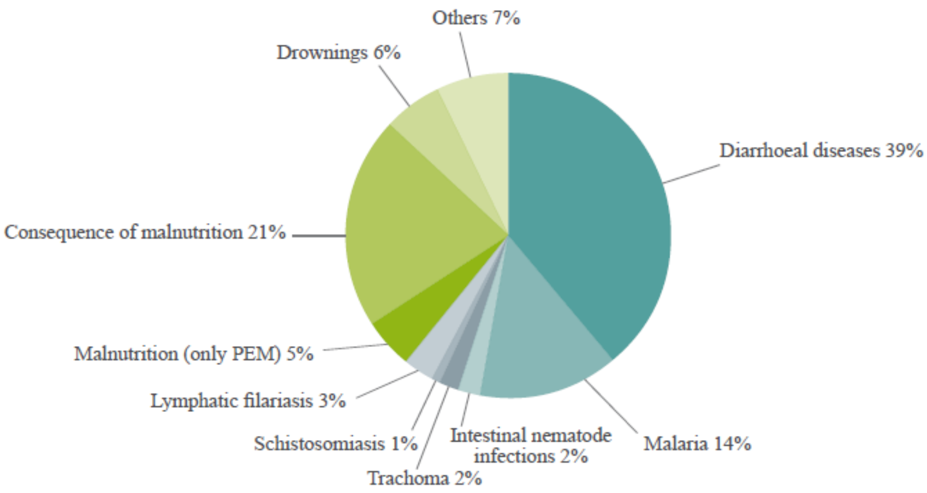
4. Disease burden of WASH

4.1 Global, regional and national disease burdens

Globally, around 1.4 million child deaths are estimated to be due to inadequate access to hygiene, sanitation and water (Prüss-Üstün *et al.* 2008). Above all, the health burden associated with inadequate WASH services falls disproportionately upon very young children (explained in more detail below). The estimated impact of improving water supply, excreta disposal, and hygiene practices for all would reduce global child mortality by a third.

Overall, WASH interventions have the potential to reduce the global disease burden (in DALYS) by 9.1% and global mortality by 6.3% (Prüss-Üstün *et al.* 2008). The vast majority of the burden of disease theoretically preventable by WASH is due to diarrhoeal diseases. In total, 64.2 million DALYs are attributed to unsafe water and poor sanitation and hygiene practices. Figure 4.1 shows estimates for the various diseases contributing to this disease burden. All of these diseases and the supporting evidence – with the exception of 'drownings' – are discussed in detail in section 5 and 6 below.

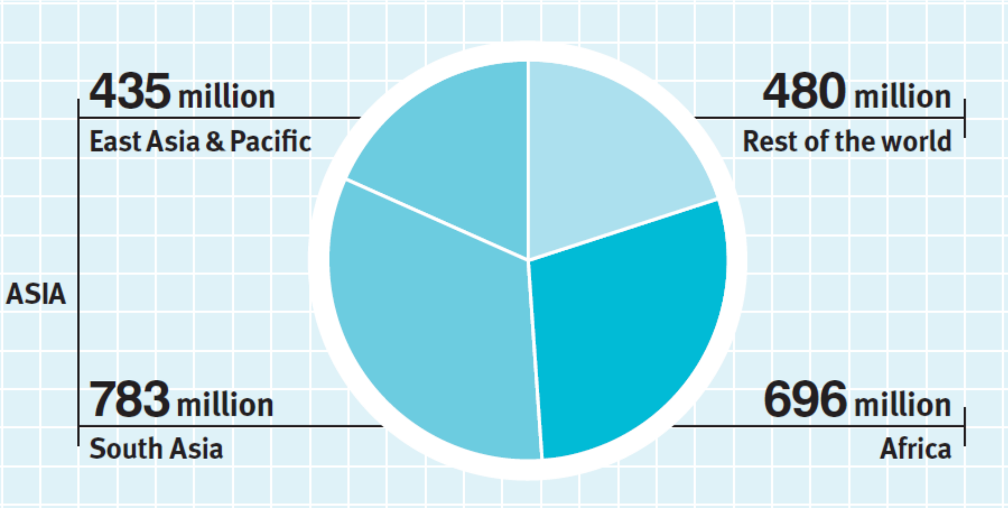
Figure 4.1 – Diseases contributing to the WASH-related disease burden



Source: Prüss-Üstün *et al.* 2008

Figure 4.2 shows the distribution of diarrhoea cases among children under five years of age and by region for 2004. Africa and South Asia account for over half the cases of childhood diarrhoea.

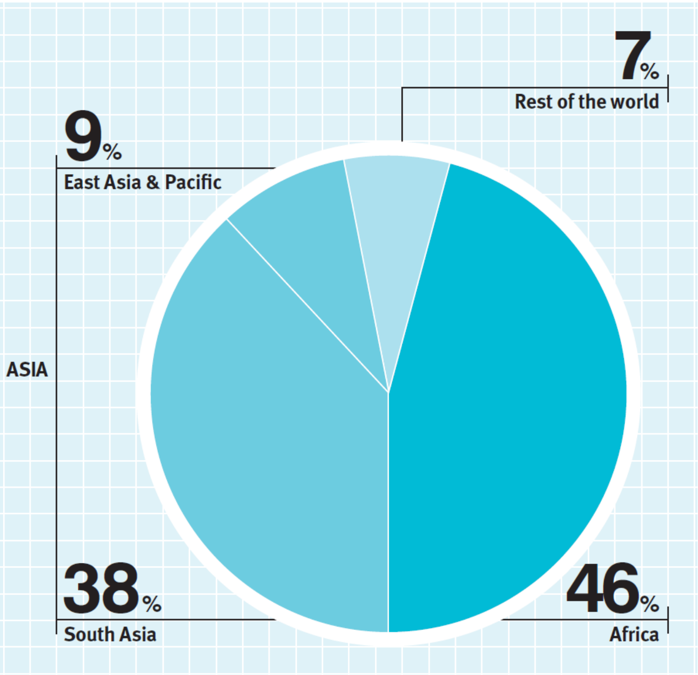
Figure 4.2 Distribution of diarrhoea cases among children under five, by region, 2004



Source: UNICEF/WHO 2009

An even greater disparity in the global distribution applies to diarrhoea deaths. The distribution of these deaths is heavily skewed toward the developing world; 80% of all under-five deaths due to diarrhoeal disease occur in sub-Saharan Africa and South Asia.

Figure 4.3 Distribution of diarrhoea deaths among children under five



Source: UNICEF/WHO 2009

The unequal global distribution of water, sanitation and hygiene-related morbidity, and especially mortality, are largely a consequence of regional differences in economic development, which impacts on the risk of water and sanitation-related diseases (especially diarrhoea) by affecting nutrition, living conditions and, last but not least, water and sanitation infrastructure. A key characteristic of the current (at times rapid) economic development in many current or former low-income countries is the often unequal distribution of economic benefits within a society and within different areas within the same country. The almost inevitable consequence is that areas left behind make little progress in combating diarrhoea.

The unequal distribution of diarrhoea deaths within countries has been widely reported (Huicho *et al.* 2006). A typical and well-documented example is India, a country with vast state-level differences in economic development and disease burden, including diarrhoea deaths (Lahariya & Paul 2010; The Million Death Study Collaborators 2010). There are less data on water and sanitation-related diseases other than diarrhoea. Since these share many risk factors with diarrhoea it can be assumed that vast regional and sub-national differences in disease burden exist. This may in particular be the case for parasitic infections such as schistosomiasis and soil-transmitted helminth infections. The prevalence and disease burden due to these two very common conditions depends on many environmental factors including sanitation infrastructure and poverty, but also soil conditions and regional climate. Recently, disease mapping using remote sensing has been used to predict geographic differences in worm infection prevalence (Brooker *et al.* 2006; Simoonga *et al.* 2009), an approach which unfortunately will remain elusive for many other water and sanitation related-infections, especially diarrhoea as its measurement almost exclusively relies on population-based data.

4.2 High risk and vulnerable populations

Poverty

The major risk factors for diarrhoea and other water, hygiene and sanitation related-diseases are related to the consequences of poverty, such as undernutrition, micronutrient deficiency, lack of adequate sanitation, scarcity of sufficient quantities of safe water, poor hygiene, low level of education and poor health care access. From this perspective it is no exaggeration to say that there is no greater risk factor for water, sanitation and hygiene related diseases than poverty, even if poverty as such is not easy to define for the purposes of estimating the disease burden. Poverty can increase the risk of infection in several dimensions: undernutrition due to lack of purchasing power increases the susceptibility to diarrhoea and many other infections (Caulfield *et al.* 2004; Rice *et al.* 2000). Poor people also have less money for health care and are often living further away from health care facilities than richer people. Poverty, especially in urban settings, is often associated with crowding which increases the likelihood of disease transmission. As a consequence, poverty in all its various forms remains the biggest challenge for the control of water, sanitation and hygiene-related diseases. Unsurprisingly, improving water, sanitation and hygiene can also help alleviate poverty. For example, adequate water access can save time and money, while reduced costs for illness and premature death can allow households to allocate their funds to more productive activities. Poverty is a very general term that is difficult to define and to address specifically. Within the large number of poor people in the world, however, there are several groups that are especially vulnerable, and these will be discussed in the following sections:

Infant and child health

It is estimated that diarrhoea kills 4,000 children every day around the world, making it the second leading cause of death among children under five globally (Black *et al.* 2003). It is estimated that 47% of children in the developing world between the ages of five and nine are infected with any of the three main types of intestinal worms as a result of inadequate sanitation. These are associated with impaired learning, increased absences from school, and decreased future economic productivity (Bethony *et al.* 2006; Clasen *et al.* 2010). Diseases such as diarrhoea, tropical enteropathy and nematode infections have negative effects on nutritional status in children. WASH interventions could be associated with improved measures of nutritional status in children: 40-60% of malnutrition is attributable to poor water, sanitation and hygiene (Prüss-Üstün & *Corvalán* 2006; Prüss-Üstün *et al.* 2008).

Water and sanitation access interact strongly with place of residence in explaining patterns of infant and child mortality. In a study of six countries in Central and West Africa, Van de Poel and colleagues (2009) found that differences in water and sanitation access (among other factors) substantially explained the variability in infant mortality between urban and rural settings. Similarly, in a study of 22 countries, Fotso and colleagues (2007) demonstrated that rapid urbanisation has resulted in poor access to safe water and as a result progress has been slow towards reducing urban child mortality.

Proper disposal of children's stools (Yeager *et al.* 1999), is an important part of many hygiene promotion campaigns and likely to benefit children. A meta-analysis of observational studies of infants' faeces disposal practices found that unsafe disposal increased the risk of diarrhoea by 23%, highlighting the importance of the safe management of both adults' and infants' faeces (Mara *et al.* 2010).

Even regarding the effect of hygiene on diarrhoea among young children in poor communities, we still have much to learn. For example, the only epidemiological evidence for the health impact of some aspects of hygiene behaviour, such as proper disposal of children's stools (Yeager *et al.* 1999), is from observational studies, which are subject to confounding factors. Intervention studies (trials) are needed to provide firm evidence. As with all behaviour change interventions, sustained behaviour change is not easy to achieve, and requires time, resources and intervention messages tailored to the local context (Curtis *et al.* 2011).

There is evidence that WASH interventions have a positive impact upon the prevalence of childhood disease (Clasen *et al.* 2010, Curtis & Cairncross 2003, Waddington *et al.* 2009, Briend 1990, Guerrant *et al.* 2008, Prüss-Üstün & *Corvalán 2006, Humphrey 2009*). For babies who are not breastfed, good hygiene, including food hygiene could be vital to increase their chances of survival by preventing diarrhoea and respiratory diseases, to which they are particularly prone (Motarjemi *et al.* 1993, Van Derslice *et al.* 1994).

Maternal and neo-natal health

Hookworm infection in pregnancy is a serious cause of morbidity for women as well as a cause of foetal development problems. Sanitation can help prevent this burden. Good access to WASH facilities also means far more convenience in terms of time and effort to collect water or to reach and use sanitation in pregnancy. Of perhaps even greater importance is adequate access to water and hygiene as a means to ensure safe delivery. Infection and sepsis are leading causes for maternal and neonatal mortality. Although the evidence base is currently not sufficient, it can be expected that a clean and hygienic environment facilitated by adequate sanitation and water access should contribute to lowering infection rates in mothers and newborn children. The recognition of good hygiene in midwifery is longstanding (MIRA Makwanpur trial team 2004; Curtis *et al.* 2011). In a study from Nepal, maternal and birth attendants handwashing behaviour was strongly associated with neonatal survival (Rhee *et al.* 2008). In a review on the effect of hygienic birth practices Blencowe and colleagues (2011) found evidence for a strong effect on neonatal tetanus and sepsis, although the quality of the reviewed studies was quite weak and included expert opinion. Ensuring accessible, affordable, reliable and good quality water, sanitation and hygiene in clinics and communities reduces maternal mortality.

Girls

Girls are a vulnerable group at risk of suffering, particularly if water, sanitation and hygiene conditions are poor. At a young age, girls are biologically less susceptible to infectious diseases, including diarrhoea, than boys. However, in many low income settings poor households often seek less health care for girls than for boys. This has especially been found to be a problem in South Asian and Southeast Asian countries with a strong boy preference that can also be seen in the high rate of gender-specific abortions in these countries. For example, in India and Bangladesh, two countries in which diarrhoea is a leading cause of death, child mortality in poor settings is often higher for girls than for boys (Claeson *et al.* 2000, Mitra *et al.* 2000, Ahmed *et al.* 2000). Differences in health care seeking behaviour have been shown to be responsible for much of this mortality gap between boys and girls. However, in areas with food scarcity, it may also be that boys are allocated more food than girls and may therefore be less susceptible to water, hygiene and sanitation related infections than girls (Koenig & D'Souza 1986), especially with regard to severe disease episodes.

Girls of school age, especially after puberty, are often faced with inadequate sanitation facilities at school, which may pose problems during menstruation and lead to school absence (Sidibe 2007). There have been some studies that indicate improving school sanitation may help girls to achieve in school (Sidibe 2007). Girls are also more often than boys charged with carrying water in areas with inadequate water access. They would therefore benefit in particular from improvements in water supply.

People living with HIV/AIDs (PLWHA)

Several studies have now documented that improvements in water quality are highly effective in reducing diarrhoea in PLWHA. Harris and colleagues (2009) found that in western Kenya point of use water treatment significantly reduced diarrhoea among breast feeding infants of HIV positive mothers before and after weaning. In a study in South Africa on morbidity in HIV positive and HIV negative mothers 24 months after delivery, Coutsoudis *et al.* (2010) found in a well-designed prospective cohort study that poor water and sanitation significantly contributed to poorer health among the HIV positive women. Similarly, a study in Nigeria found a 46% reduction in diarrhoea among people living with HIV following a point of use water treatment intervention, even though over 80% already had improved water supplies (Barzilay *et al.* 2011) although the study lacked an adequate control group. WASH can protect the very young and those infected with HIV from opportunistic infections such as diarrhoea and skin diseases. One randomised trial, providing people living with HIV/AIDS with guidance on household water treatment and safe storage, reduced the number of days they had diarrhoea by 33% (Lule *et al.* 2005). Although empirical studies have suggested that the effect of household water treatment on diarrhoea may be smaller than observed, its effect could be important in PLWHA because of their high susceptibility to infections that would not cause illness in healthy individuals. Further research is needed on this issue.

5. Health impacts of WASH: diarrhoeal diseases

The following two sections consider the diseases associated with lack of access to WASH and the impact of WASH interventions on the risk for these diseases.

This section considers diarrhoeal diseases. Firstly, the diarrhoeal disease burdens associated with WASH and then, more specifically, that associated epidemic diarrhoeal diseases are considered. Secondly, the systematic review literature for the effect on WASH interventions on diarrhoeal disease morbidity is discussed. The strong focus on diarrhoeal diseases reflects both its importance in terms of the associated disease burden but also that diarrhoea offers the most extensive body of evidence for the health impacts of WASH.

Section 6 below will consider other attributable diseases and assesses the available evidence for health impacts.

5.1 WASH and diarrhoeal diseases

Diarrhoeal diseases are a symptom most often caused by infectious agents such as bacteria (e.g. *E. coli*, *salmonella*, *shigella*, *campylobacter*), viruses (e.g. rotaviruses, noroviruses and adenoviruses), protozoa (e.g. amoeba, cryptosporidium and gardia) (WHO 1999). Only a small fraction of diarrhoea is caused by non-infectious conditions such as intoxication or non-infectious inflammatory diseases. As was discussed previously, it is important to note the differing aetiologies and dominant transmission pathways for diarrhoeal diseases.

Diarrhoeal diseases are one of the leading causes of morbidity and mortality among children under five years of age in both low- and middle-income countries (Black *et al.* 2010). Approximately 1.9 million children under five years of age died from diarrhoeal diseases in the year 2004.

Diarrhoea – 88% of which is due to poor water and sanitation (WHO 2004) – kills more children than HIV/AIDS, malaria and measles combined (UNICEF/WHO 2009). By the most recent authoritative estimates, diarrhoea is the leading cause of death among children under five years in sub-Saharan Africa, resulting in 19% of all deaths in this age group (Black *et al.* 2010).

Diarrhoeal diseases account for 52 million DALYs (WHO 2008). It is estimated that each child under the age of five in the developing world experiences three episodes of diarrhoea per year (Kosek *et al.* 2003). Within low-income countries, the very poor suffer much more from diarrhoea than others, an aspect which becomes increasingly obvious due to the widening income gap in many rapidly developing countries. The majority of fatal cases of diarrhoea are among children under five.

The focus on acute diarrhoea almost certainly underestimates the disease burden caused by inadequate water and sanitation: it is important to consider long-term as well as short-term effects. Many excreta-related pathogens cause diarrhoea and also impair intestinal absorption, both of which contribute to malnutrition. Repeated infection with enteric pathogens may have a lasting impact on the growth and development of a child (Checkley *et al.* 2008; Lima *et al.* 2000). These long-term consequences could manifest themselves in the form of stunting and cognitive impairment (Petri *et al.* 2008). It has been suggested that 50% of childhood undernutrition is caused by repeated diarrhoea or intestinal nematode infections as a result of unsafe WASH (Prüss-Üstün *et al.* 2008). Due to methodological issues, especially socio-economic confounding, the extent to which diarrhoea contributes to undernutrition and growth faltering is still under debate, but a substantial role remains likely (Humphrey 2009).

The widespread introduction of oral rehydration therapy (ORT) in the 1980s contributed much to reducing mortality from diarrhoeal disease. However, such interventions focus on mortality rather than morbidity and on secondary, rather than primary, prevention. Moreover, ORT does not address the problems of persistent diarrhoea and dysentery (Bartram & Cairncross 2010), which can contribute to undernutrition with all its adverse health consequences. More recently, vaccination against rota virus (a major cause of severe acute diarrhoea) has demonstrated promising clinical effectiveness but, as with most vaccines, it targets only single organisms. These interventions are important, but cannot replace the need for WASH interventions that have the potential for achieving a broad impact on multiple diarrhoea pathogens by targeting the major transmission pathways.

As diarrhoea pathogens spread by many different interacting pathways, WASH interventions need to be well coordinated to be effective, although evidence is lacking on how best to combine different approaches. There is little doubt, however, that improving access to adequate amounts of water, hygienic sanitation facilities and promotion of handwashing with soap should be the cornerstones of integrated campaigns (Cairncross *et al.* 2010b).

Sanitation and hygiene promotion are the two most effective interventions for controlling endemic diarrhoea and the most cost-effective (approximately US$3 per DALY averted for hygiene promotion and US$11 for sanitation promotion), ranking higher on this basis than any other form of health intervention, such as combating malaria, tuberculosis and HIV/AIDS (Laxminarayan *et al.* 2006).

A further potentially very important intervention (largely neglected in terms of research and public health investment) would be to improve food hygiene, which may prevent many diarrhoea deaths, especially in hot climates where food hygiene is difficult to maintain (Curtis *et al.* 2011). A recent prospective cohort study by Luby and colleagues (2011) suggests that handwashing with soap before preparation of children's food may be particularly effective in reducing diarrhoea. A recent intervention study (Touré *et al.* 2011) found both high baseline faecal contamination of weaning foods and large reductions in contamination following a targeted hygiene intervention. More research is needed to establish the effectiveness of promoting improved food hygiene, particularly the hygiene of weaning foods, eaten by children in the age range most vulnerable to diarrhoeal disease. The impact of better food hygiene upon health outcomes may be considerable.

Conclusion: There is good evidence that inadequate WASH contributes substantially to the burden of diarrhoea and its related adverse health effects.

5.2 WASH and epidemic diarrhoeal disease (cholera and typhoid)

Most of the diarrhoeal diseases associated with poor access to sanitation, hygiene and water tend to be endemic as people are exposed on a more or less continuous basis to pathogens as a result of poor WASH. However, there are important exceptions to this where WASH-associated diseases are epidemic in nature. Notable among these are cholera (*Vibrio cholerae*) and typhoid fever (*Salmonella typhi*). Recent large scale outbreaks of cholera in Haiti (2010), Pakistan (2010) and Zimbabwe (2008/9) and of typhoid fever in Kinshasha in the Democratic Republic of Congo (2004) have caused high mortality, especially as they often occur at times of war and natural disaster, with crowded conditions, poor or reduced access to WASH, and weakened or no access to healthcare.

Cholera is a disease that is strongly associated with poverty and thrives in areas of poor WASH. Historically, outbreaks have occurred following wars, civil unrest and natural disasters. Cholera is a persistent public health problem in many parts of the world. In 2010, 317,534 cases of cholera were reported including over 7,500 deaths, a mortality ratio of 2.38% (WHO 2010a). The year represented a significant increase in cholera cases and death, mainly as a result of the cholera outbreak in Haiti. Until 2010, over 90% of all reported cholera cases and deaths occurred in Africa (Gaffga *et al.* 2007). Despite the widespread use of oral rehydration solution (ORS), the case fatality rate remains highest in Africa. Furthermore the continent suffers from explosive outbreaks that result in high levels of both morbidity and mortality. The epidemic in northern Kivu, Democratic Republic of Congo, is a haunting reminder of the disease's virulence; approximately 50,000 Rwandan refugees perished within one month. Although cholera is a notifiable disease, the WHO estimates that only 5-10% of actual cases worldwide are reported due to inadequate surveillance systems and economic concerns (Gaffga *et al.* 2007).

The principal reservoirs of cholera are humans and sources of brackish water such as estuaries. Transmission can occur either through the direct consumption of water from a confirmed aquatic reservoir or the ingestion of poorly cooked and contaminated fauna or flora. Although cholera, is largely perceived as a waterborne disease, person-to-person transmission, limited access to sanitation, an inadequate water supply and poor hygienic practices may contribute to the rapid progression of an epidemic. Although WHO recommends improvements in water supply and sanitation, this approach is not always implemented nor indeed feasible for low-income countries, especially after an outbreak has begun (WHO 2009). Specific control measures promoted by the WHO are: safe drinking water, sanitation, personal hygiene, health education and food safety.

Evidently, cholera and typhoid fever epidemics require the same interventions used to prevent and control endemic diarrhoeal diseases; however the evidence supporting the effectiveness of WASH interventions against cholera or typhoid is limited. Currently no systematic literature reviews exist documenting the impact of the different WASH interventions on cholera or typhoid fever.

A systematic literature review was conducted for ECHO on the effectiveness of WASH interventions for cholera control in Africa during epidemics (LSHTM 2009) and will be expanded in 2012 to include all other regions. The 2009 review found that, following the application of the minimum evaluation procedures set out by the WHO (1983), only eight papers met the specified criteria. Of the eight articles identified, seven were water quality interventions and one was a health education and hygiene study, and only two had a health outcome. This highlights two salient points: firstly that, although cholera is a huge problem for Africa, there is very limited evidence on the effectiveness of different WASH interventions to control it; and secondly, that interventions almost exclusively seem to focus on water quality improvements, ignoring the other transmission routes. The review also found limited involvement of local communities in the water quality interventions with the result that uptake of the interventions was poor.

The importance of local involvement, appropriate technology, and understanding of the local cholera reservoir was shown in Bangladesh, where sarees were used to filter drinking water before consumption yielded a 48% reduction in cholera (Colwell 2003). In the same part of the country five years later a study found 31% of the population still filtering their drinking water, of which 61% still used sarees (Huq 2010).

The nature of cholera, but also typhoid fever outbreaks, combined with the high mortality associated with them, does not always allow for well-designed intervention studies. However, the seriousness of these outbreaks, together with the financial resources spent by local governments and international aid agencies, warrants more research on the impact of the different WASH interventions and their implementation strategies on cholera and typhoid fever.

5.3 Systematic reviews for the effect of WASH on diarrhoeal morbidity

Several systematic reviews have assessed the impact on health of a range of WASH interventions that are classified in different ways. The studies reviewed include a range of outcome indicators, but the common and perhaps most important of these is diarrhoeal disease morbidity. Several studies also explore combinations of these interventions. The results from the studies which highlight the impact of WASH interventions on diarrhoea morbidity are laid out in Table 5.1.

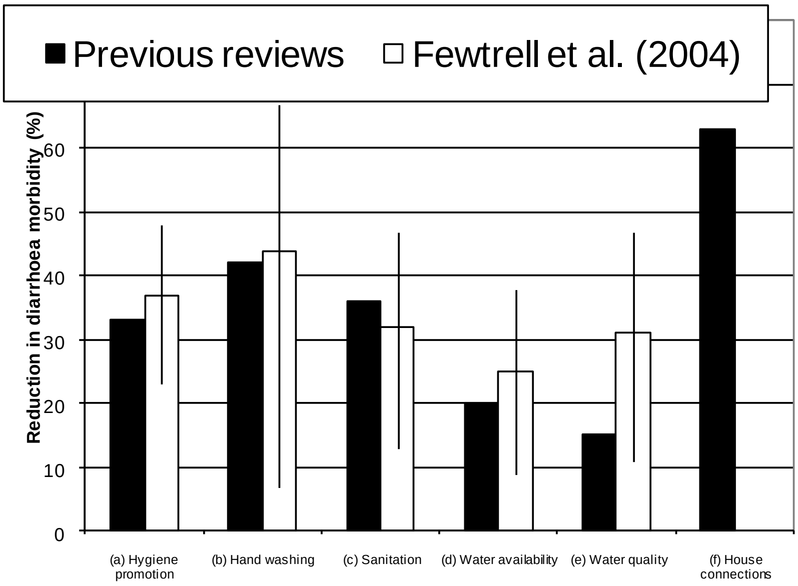
Table 5.1 Percentage decrease in risk of diarrhoea attributed to single and combined WASH interventions, as specified in systematic reviews

Study	Interventions	Risk reduction (%)
Esrey *et al.* 1985	Water quality	16% (median)
	Water quantity	25% (median)
	Water quality & quantity	37% (median)
	Sanitation	22% (median)
Esrey *et al.* 1991	Water quantity	20% (median)
	Water quality	15% (median)
	Water quality and quantity	17% (median)
	Sanitation	36% (median)
	Water and sanitation	30% (median)
	Hygiene promotion	33% (median)
Curtis & Cairncross 2003	Handwashing with soap	42-47%(pooled est)
Fewtrell *et al.* 2005a [1]	Water supply	25% (pooled estimate)
	Water quality	31% (pooled estimate)
	Sanitation	32% (pooled estimate)
	Hygiene education	28% (pooled estimate)
	Handwashing	44% (pooled estimate)
	Multiple interventions	33% (pooled estimate)
Waddington *et al.* 2009	Water supply *pooled*	2% (pooled estimate)
	Water quality *pooled*	21% (pooled estimate)
	Sanitation *pooled*	37% (pooled estimate)
	Hygiene *pooled*	31% (pooled estimate)
	Water supply & san/hyg	38% (pooled estimate)
	Water quality & san/hyg	57% (pooled estimate)
Cairncross *et al.* 2010a [2]	Handwashing with soap	48% (pooled estimate)
	Water quality	17% (pooled estimate)
	Excreta disposal	36% (pooled estimate)

[1] *Includes all studies, both poor and adequate quality*
[2] *Disease reductions listed are ones chosen for the LiST model*

Limitations of this literature
The review by Fewtrell *et al.* (2005) was the first to add confidence intervals. The wide range of uncertainty about any of the reductions shown is demonstrated by the overlapping confidence intervals (vertical lines) shown in Figure 3.1. which adds a later pooled estimate with confidence intervals from a separate systematic review of handwashing with soap (Curtis & Cairncross 2003).

Figure 5.1 Results of reviews of the effect on diarrhoea of WASH interventions



Previous reviews a,c–f: Esrey et al.(1991); b: Curtis & Cairncross (2003)

Source: Bartram & Cairncross 2010

The width of the confidence intervals is a consequence of the variation between individual studies caused by many different factors, not least the local context. For example, some reviews would consider a comparison between in-house water taps and a public well in the same category as a comparison between a public well with a lining and a hand pump on one hand, and a public well with no lining on the other, since both are water supply improvements.

Another potential source of variation is the methodological deficiencies in most of the studies reviewed. A paper published in 1983 classified these shortcomings into eight categories and concluded that of some 50 studies examined, all were subject to at least one deficiency (Blum & Feachem 1983). This shouldn't necessarily be interpreted as a lack of care on the part of the researchers, but rather as a reflection of the necessary compromise between the ideal of the perfectly rigorous study (internal validity) and the need for research findings that are relevant to the real world (external validity).

One thing is clear; the estimates of effect size reached by the older literature reviews all lie squarely within the ranges of uncertainty calculated by Fewtrell. So while there was much interest in the difference between Fewtrell's findings and those of the previous review by Esrey, these differences were not statistically significant.

The real ranges of uncertainty are greater than shown by the lines in Figure 3.1. Fewtrell's confidence intervals are based only upon the heterogeneity between studies, and do not take account of confounding or bias. For example, a consistent bias due to placebo effect or the desire of respondents to please the fieldworkers in trials.

A further problem with the literature is that few of the studies set out to evaluate more than one of the WASH interventions. For example, the recent Cochrane review of the health impact of excreta disposal (Clasen *et al.* 2010) found hardly any studies of sanitation alone without a simultaneous water supply intervention.

Much of the discussion of the results of these reviews pays scant regard to these, and other, shortcomings. For example, a number of authors have commented that the health impact of combined interventions such as sanitation plus water supply is no greater than the impact of a single intervention. This apparent anomaly becomes clear when it is understood that the comparison is not between studies of combined interventions and studies of single interventions, but between studies of combined interventions and other studies of combined interventions.

Evidence for mortality impacts

It should be noted that almost all of the studies in the literature have measured impact on morbidity, not mortality, although it is the deaths caused by diarrhoea that account for most of the DALYs lost through the disease (Rosen & Vincent 2001).
There are serious ethical and logistical difficulties in carrying out a study to measure the impact of water supply and sanitation on child mortality. Nevertheless, two studies stand out; both looked at deaths due to diarrhoea, and by coincidence both are Brazilian. The results are in Table 5.2. and Table 5.3.

Table 5.2 Water supplies in Palmares, north-east Brazil (infants < 4 months)

Type of Water Supply	% of deaths due to diarrhoea
Public piped system: (60% of population)	
- house connections	20.0
- tap < 100 m from house	57.1
- tap > 100 m from house	68.0
Unprotected well: (40% of population)	57.6

Source: Wagner & Lanoix 1959

The first study is based on routine reporting of cause of death among very young children in north-east Brazil. The proportion of child deaths due to diarrhoea is much greater when they do not have water piped into the home. The authors of the book in which this example appears (Wagner & Lanoix 1959) suggest that the higher death rate from diarrhoea among children whose water comes from outside is caused by faecal contamination of the water while it is being carried in. A more modern interpretation would note that people who have to carry water home use less of it for hygiene.

Table 5.3. Effect on child diarrhoea mortality of sanitation, water quality and access to water in Pelotas, southern Brazil

Environmental variables	Cases	Controls	Relative risk (a)	(b)	(c)
Availability of piped water					
Piped in house	59	168	1.0	1.0	
Piped to plot	52	91	1.9	1.5	(0.8–3.0)
Other	59	81	5.5	4.8	(1.7–13.8)
χ^2(2 df)			21.81†	9.36†	
Type of water					
Treated	146	303	1.0	1.0	
Untreated	24	37	2.5	1.4	(0.3–6.1)
χ^2(1 df)			2.66	0.25	
Type of toilet					
Flush	69	177	1.0	1.0	
Pit latrine	92	146	2.3	1.1	(0.5–2.3)
None	9	17	1.7	0.7	(0.2–2.5)
χ^2(2 df)			10.29†	0.92	
Type of house					
Well built	83	220	1.0	1.0	
Shack	87	120	2.5	1.9	(1.0–3.6)
χ^2(1 df)			13.45‡	3.77	
Crowding (no./bedroom)					
≤2.5	32	83	1.0	1.0	
2.6–	42	97	1.0	0.8	(0.4–1.7)
3.1–	44	88	1.3	1.0	(0.5–2.2)
5.0+	52	72	1.9	1.2	(0.5–2.5)
χ^2(1 df trend)			5.20*	0.45	

(a) adjusted for age only.
(b) adjusted for age, social status, type of milk consumed and all other environmental variables listed in the Table.
(c) 95% confidence interval for (b) above.
* $p<0.05$; † $p<0.01$, ‡ $p<0.001$.

Source: Victora *et al.* 1988

This second study is a more recent case-controlled study. Data were collected on children who had died in the city of Pelotas in the previous year and each child was compared with another one still alive who lived nearby. Instead of comparing death rates between children with and without water supply, the researchers compared the proportions with water supply between the living and the dead children.

Both studies draw a picture that is broadly similar with the findings of the randomised and quasi-randomised studies of morbidity presented above. The two studies show major health benefits from house connections or from water pipes near the house, but show a surprisingly small impact from water quality. They do not shed much light on the benefits of sanitation.

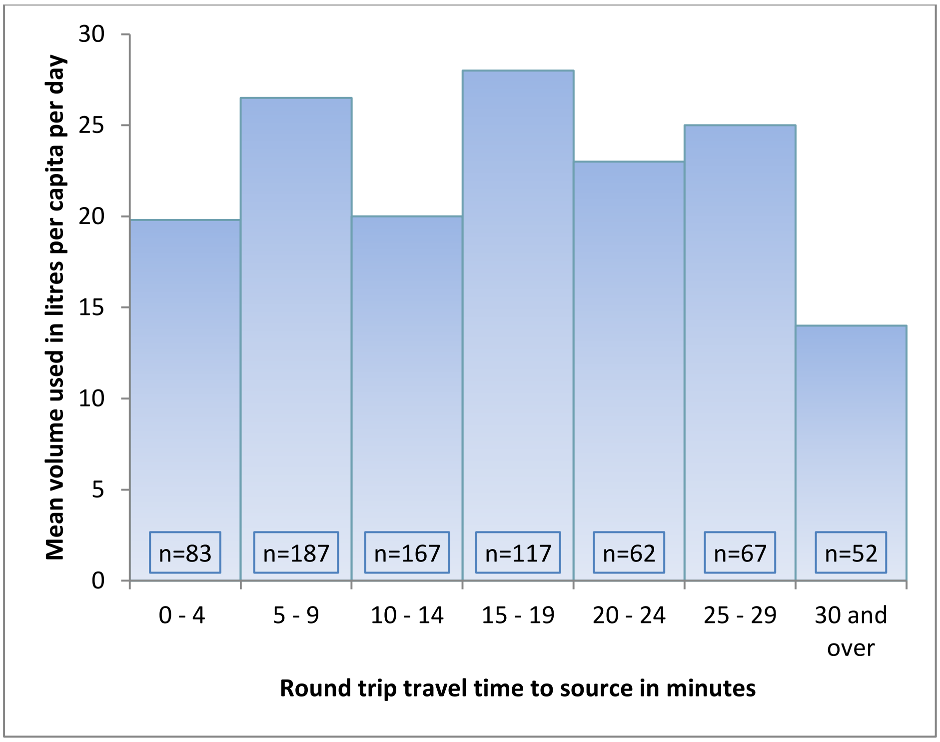
The distance/consumption plateau and its implications

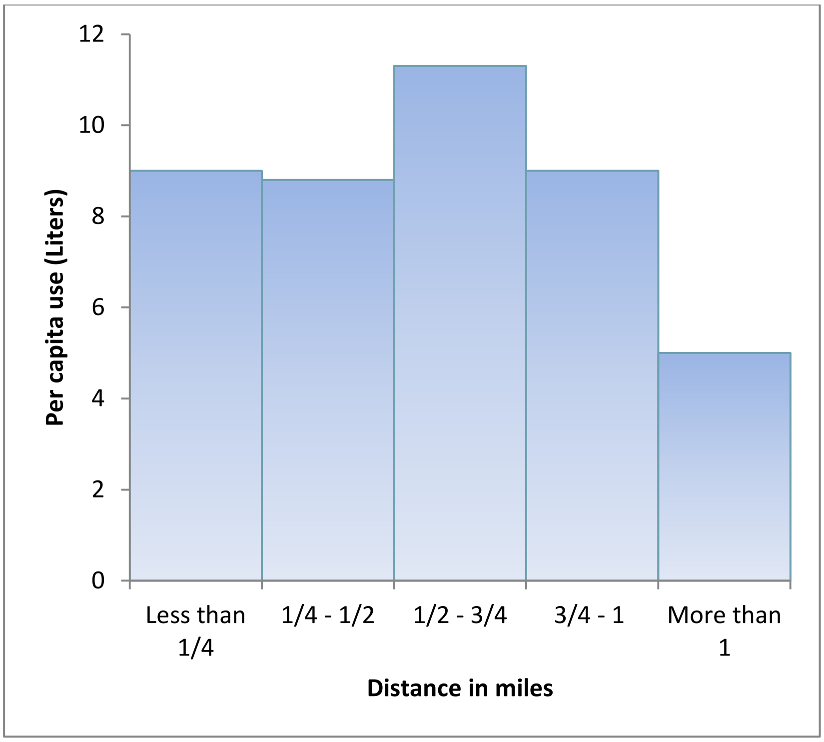
One way to make sense of the data, having noted that many projects heavily based on water quality improvement failed to produce a health impact, is to conclude that health impact depends more strongly on water quantity, itself an indicator of hygiene. This puts water consumption at the centre of the model; on the one hand it is the indicator of hygiene (other things being equal) and on the other it is the result of the level of access to water.

Water consumption changes with access to water in a partly counter-intuitive way. When water sources are more than half an hour's return journey away from home, then provision of water closer to the home will lead almost automatically to water consumption increases, but sources closer to the home than a 30 minute round-trip will be used for almost the same amount of water whether the distance is 1,000 metres or 100 metres (see Figure 5.2). This inelasticity of demand with distance is sometimes termed the water use plateau. By contrast, when water is piped into the house or yard, consumption doubles or trebles (not shown in Figure 5.2).

Figure 5.2 Relationship between distance to water and water consumption in (a) Eastern and (b) Southern Africa

Note: walking at 4 kilometres per hour for a round-trip journey time of 30 minutes (Figure A) is equivalent to a one way distance of 1 kilometre or 0.75 miles (Figure B)





Sources: (a) White *et al.* 1972 (b) Feachem *et al.* 1978.

The implication is that, other things being equal, priority in the allocation of water supplies should go to those people whose existing source is more than a 30-minute round-trip walk away. Closer water supplies will lead their consumption to increase – hence their hygiene to improve – and they will therefore be more likely to show a health benefit.

The evidence for this paradigm is not stronger than that for other WASH interventions; two recent systematic reviews (Wang & Hunter 2010, Subaiya & Cairncross 2011) support the hypothesis that reduced water collection journey time is associated with reduced disease risk, especially when the reduction is from more than 30 minutes.

The same people (living more than 30 minutes from water) will also benefit most from the saving in time and drudgery when water sources are provided closer to their homes. Moreover, because of this they will be more likely to be willing to contribute towards the cost of the water supply, assuming that sustainable institutional arrangements have been made to collect their payment and manage the funds.

If everyone is already on the plateau (if everyone has water within 30 minutes of their home) then provision of water through public taps or pumps on wells will move people along the plateau, but not lead to increased consumption. Thus they are unlikely to show any health benefit. In such a case, consideration should be given to the provision of house connections if a health benefit is desired. For a system managed by a low-income community such as an African village, cost recovery is also much easier when some house connections are provided, because defaulters can easily be disconnected. Applying such sanctions to the users of public standpipes is much more difficult, but the revenue from a small minority of house connections is usually enough to provide free standpipe water to the rest of the community.

However in other settings, such as urban apartments with cistern-flush toilets, many people are dependent upon house connections for their continued wellbeing; in such environments, disconnection of a house connection could be a serious infringement of the consumer's human rights, and possibly illegal.

Nevertheless, the policy implications of the Water Use Plateau are best read together with the impact of house connections. One way to adopt them would be to set a water supply target for household/yard access wherever possible (while not placing the achievement of this for a minority above the achievement of 30 minutes access for all).

Conclusion:

There is suggestive evidence that hygiene (i.e. handwashing) substantially reduces diarrhoea diseases in the community. There is suggestive evidence that sanitation, and household water treatment can reduce diarrhoea. There is suggestive evidence that increasing water quantity directly reduces the risk of diarrhoea and other WASH related diseases. Few studies have looked at the effect of water, sanitation and hygiene interventions on mortality, and these have not been of good quality. Therefore, there is currently only weak epidemiological evidence that WASH interventions reduce mortality, even if biological plausibility remains high. The effect on health of different WASH interventions is likely to extend to a large variety of infectious diseases such as worm infections, trachoma, acute respiratory infections and most importantly diarrhoea.

A clean environment by ensuring access to water, sanitation and hygiene has historically been a key to improving health and survival in countries now regarded as developed. There is little evidence to suggest that equally impressive improvements in health and longevity cannot be achieved in low income settings today by effective and sustainable WASH interventions.

6. Other health impacts

In this section the following other diseases associated with WASH are discussed and the evidence considered:

Where appropriate, systematic searches were completed and the findings are summarised in tables given in the annexes.

6.1 Acute respiratory infections

Growing attention is being paid to the important role of WASH interventions in preventing the transmission of respiratory pathogens. Causing 4.2 million deaths each year (1.6 million among children under five years), acute respiratory infections (ARI) are the global leading cause of child mortality (Black et al 2010).

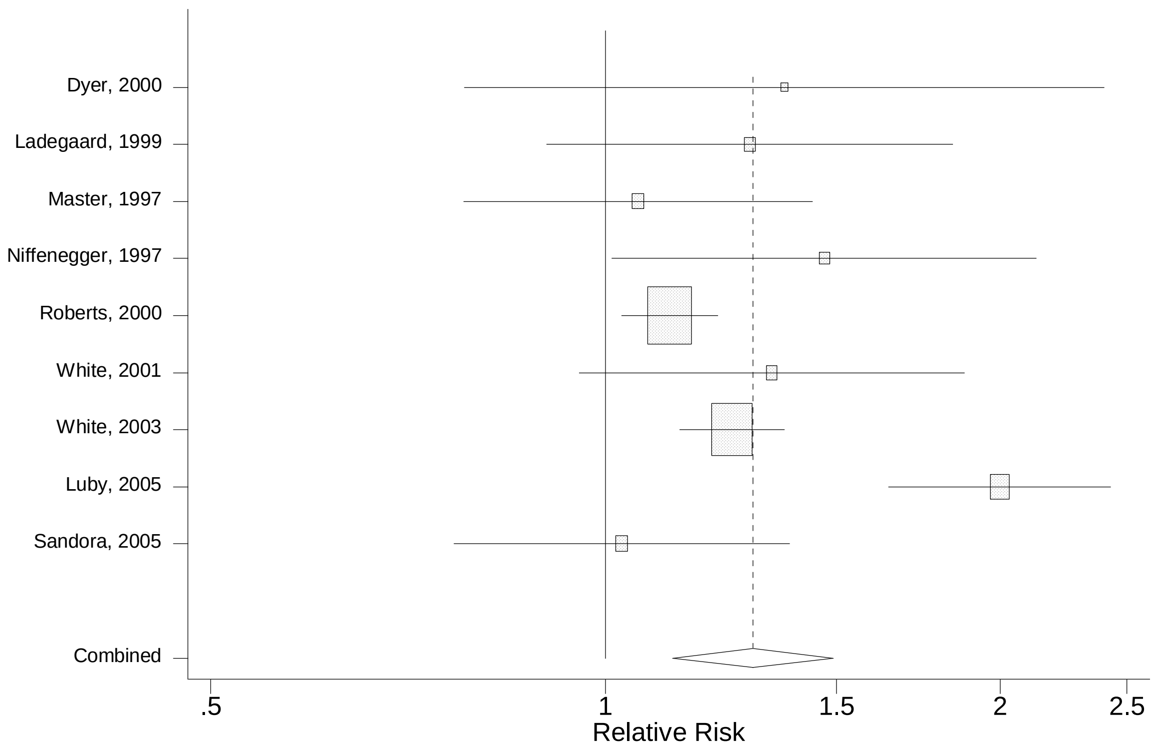
A systematic review of the effect of handwashing with soap on ARI found, after updating (see Figure 6.1), a pooled estimate of 23% risk reduction (Rabie & Curtis 2006). Another meta-analysis of improved hand hygiene by Aiello and colleagues (2008) found a similar effect estimate of 21% risk reduction (Aiello et al 2008).

Of the studies included in these two reviews, all but one were conducted in high- or middle-income settings; the one study conducted in a low-income setting found a 50% risk reduction for ARI (Luby et al 2005). Methodological issues with this study, including a lack of blinding, no clinical case confirmation, and those delivering the intervention also recording the outcome, may mean that the large effect is the result of systematic error (bias). However, Rabie and Curtis considered that all the studies included in their meta-analysis had one or several methodological flaws.

Two more recent studies have taken place in low/middle income settings and were not included in these reviews (Rabie & Curtis 2006; Aiello et al 2008). Bowen and colleagues (2007) found that an intensive hand hygiene promotion campaign decreased significantly the incidence of all illnesses and absenteeism among Chinese school children, without observing a significant impact on respiratory illnesses specifically. More recently in Egypt, an intervention study in 60 elementary schooled showed a reduction of 40% of absenteeism due to influenza-like illnesses, and a reduction of 50% of absenteeism due to laboratory confirmed influenza cases (Talaat et al., 2011).

While the evidence reported by Luby may be an outlier, laboratory and several field studies have shown that hand hygiene can play a role in reducing the transmission of influenza and respiratory syncytial viruses, both leading causes of severe respiratory infections in children worldwide (Fung & Cairncross 2007; Cowling et al. 2009; Goldmann 2000). A recently updated Cochrane review concludes that handwashing with soap is one of the effective physical interventions to reduce the spread of viral respiratory infections (Jefferson et al., 2011).

Figure 6.1 Risk of respiratory infection and handwashing with soap
Risk Reduction: RR=1.295 (95% confidence interval = 1.125 -1.492)
[RR = 1.19 (95% confidence interval = 1.12 – 1.26) if retaining the first 7 studies (excluding Luby and Sandora), which results are statistically homogenous for random effect pooling]



Source: Adapted from Rabie and Curtis 2006, including Luby *et al.*(2005) and Sandora *et al.* 2005. Updated by authors.

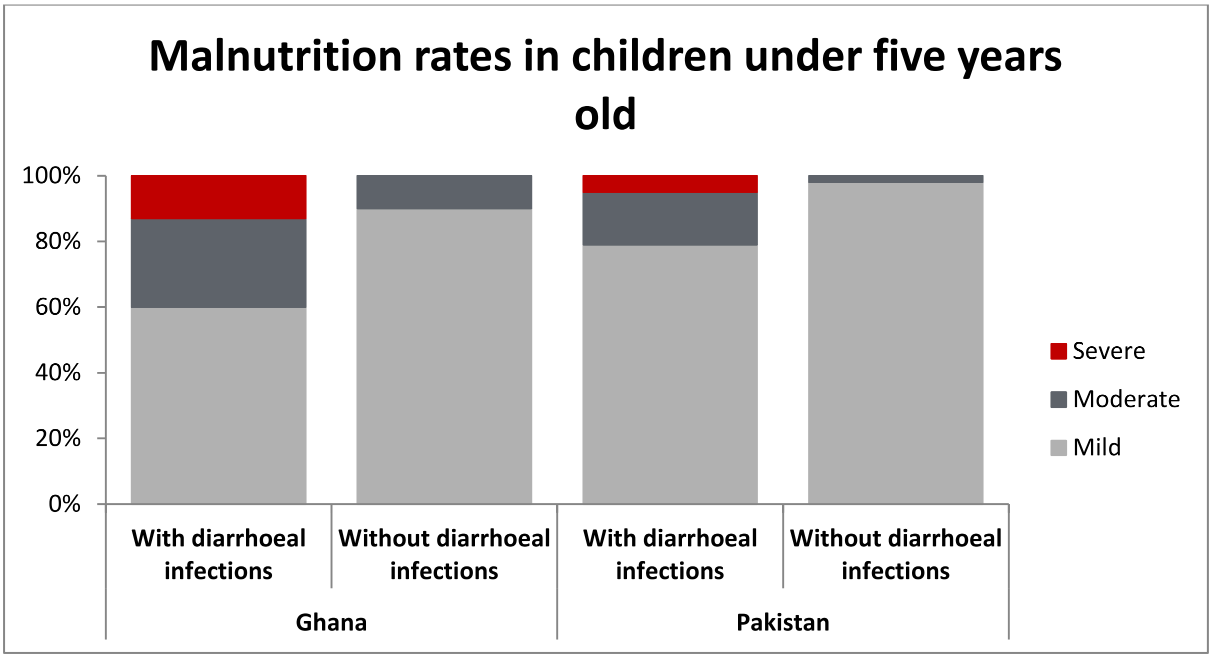
Conclusion: There is good evidence that improved hygiene can reduce the risk of selected viral respiratory infections.

6.2 Undernutrition

It is estimated that undernutrition causes 2.2 million deaths and 21% of global disease burden for children younger than five years (Black *et al*. 2008). Undernutrition is both a cause and a consequence of diarrhoea. Undernutrition increases both the susceptibility to diarrhoea *and* the severity of episodes, and WASH-related pathogens (especially those causing diarrhoea) lead to reduced food intake and the malabsorption of nutrients (Checkley *et al.* 2008; Lima *et al.* 2000). As diarrhoea causes undernutrition, it further reduces a child's resistance to subsequent infections creating a vicious circle (Brown *et al.* 2003).

Evidence suggests that exposure to excreta-related pathogens, including worms, and repeated episodes of diarrhoea in early life leads to lowered immunity, increased morbidity, and largely irreversible growth and cognitive deficits (Petri *et al.* 2008; Prüss-Üstün & *Corvalán* 2006; World Bank 2006).

Figure 6.2 Linking diarrhoea and malnutrition in children under five in Ghana and Pakistan



Source: **Adapted from Acharya & Paunio (2008)**

It has been estimated that if the impacts of this chronic burden are taken into consideration, the global disease burden due to diarrhoea (and, consequently, to lack of access to safe WASH) would be about twice current estimates that consider only acute illness and mortality (Guerrant *et al.* 2002).

Overall, it has been estimated that 50% of the consequences of undernutrition are caused by environmental factors that include poor hygiene and lack of access to water supply and sanitation (Blössner & de Onis 2005; Prüss-Üstün & *Corvalán* 2006; World Bank 2008; Victora & Fall 2008).For example, when undernourished children are recovering from an episode of diarrhoea, they are unusually susceptible to pneumonia (Schmidt *et al.* 2009b).

More recently it has been hypothesised that a key cause of child undernutrition is a subclinical disorder of the small intestine known as tropical enteropathy or environmental enteropathy (EE). This condition is characterised by malabsorption and increased gut permeability which allows microbes to pass across the intestinal wall into blood circulation and chronically trigger immune activation which, in turn, suppresses growth. EE may be caused by ingesting large quantities of faecal contamination (Humphrey 2009). Accordingly, improved WASH may enhance child growth by reducing or preventing EE. Indeed, Humphrey has posited that the primary pathway by which poor WASH leads to undernutrition is EE and not diarrhoea – a hypothesis that is currently being tested in three large trials in Zimbabwe, Kenya, and Bangladesh.

Impaired gut function as a consequence of recurrent enteric infections may also reduce the effectiveness of vaccines. The gut contains a vast and complex immune system that influences the immune response in the rest of the body. Frequent enteric infections have been shown to reduce the immunogenicity and therefore the protective effect of vaccines (Levine 2010).

A forthcoming Cochrane review for the effect of WASH on undernutrition found relatively few high quality interventions studies, with most studies included being ranked as poor quality (Dangour et al 2011). One higher quality study – a randomised controlled trial - for the effect for water treatment on stunting found an average 0.8 cm gain among the treatment arm (95% CI 0.7 - 1.6 cm; P-value = 0.031) (Du Preez et al 2011). In a non-randomised study of low quality conducted in Ethiopia some communities received WASH education and hardware (e.g. pit latrines and new water sources) while others received no interventions. Between the beginning and end of the 5-year project, mean height-for-age Z-score among children < 5 years increased (+0·33; P-value = 0·02) and the prevalence of stunting declined by 12% in the WASH communities, but these indicators did not change in the control communities (Fenn et al 2012). The results of this review are given in Annex 2.

The need for more high quality studies investigating the effect of improved WASH on childhood nutrition is being met by a number of trials that are currently underway in India, Bangladesh, Kenya and Zimbabwe (see Box 6.1).

Box 6.1 A cluster-randomised control trial for environmental enteropathy

A cluster-randomised control trial with a factorial design is being led by the Zimbabwe Ministry of Health and Child Welfare and Zvitambo Project in collaboration with Johns Hopkins Bloomberg School of Public Health, Cornell University, the London School of Hygiene and Tropical Medicine, and the Research Institute of the McGill University Health Centres. The study is funded by DFID, the Bill and Melinda Gates Foundation, USA National Institutes of Health, and Wellcome Trust.

The trial will evaluate the independent and combined effects of improved water, sanitation and hygiene, and improved infant diet on child growth and anemia between birth and 18 months of age.

This study aims to answer the following question:

“If faecal-oral transmission is prevented among infants, will linear growth improve?”

Conclusion: There is suggestive evidence that poor WASH is associated with undernutrition. More high quality evidence is needed for the effect of WASH in reducing undernutrition and to identify the most important exposures.

6.3 Neglected Tropical Diseases

A number of diseases of poverty, known as the Neglected Tropical Diseases (NTDs), cause substantial chronic suffering and DALY losses in developing countries, out of all proportion to the number of deaths they cause (Brown 2003). The following NTDs can be prevented by improvements in water, sanitation, and hygiene: trachoma, schistosomiasis, soil-transmitted helminths, neglected zoonoses, dengue haemorrhagic fever, dracunculiasis (guinea-worm disease), and lymphatic filariasis (elephantiasis).

Current efforts to eliminate many of these diseases often focus on mass drug administration (MDA) programmes, which are more expensive and less sustainable than WASH interventions. If efforts focussed more on integrating environmental improvements, i.e. WASH improvements, with MDA, greater progress would be made in reducing the burden of these illnesses.

Esrey and colleagues (1991) calculated disease-specific median reduction levels for a number of these infections. The median reduction percentage in morbidity and mortality from improved water and sanitation were 29% for ascariasis, 26% for Guinea worm, 77% for schistosomiasis, and 27% for trachoma.

The following NTDs are discussed in more detail in this section: soil-transmitted helminth infections, trachoma, schistosomiasis and guinea worm. Lymphatic filariasis and dengue are discussed in section 6.4.

6.3.1 Soil-transmitted helminth infections

Soil-transmitted helminth infections related to inadequate WASH result in undernutrition, anaemia and impaired development. According to Bethony and colleagues (2006) the major soil-transmitted intestinal helminth (STH) infections affect large populations across the developing world: between 800 million and 1.2 billion infected with *Ascaris lumbricoides* (roundworm); between 600 and 800 million infected with *Trichuris trichiura* (whipworm) and between 575 and 750 million with hookworm (*Necator americanus* and *Ancylostoma duodenale*). The global health impact of these infections remains debated, with estimates ranging between 4 and 39 million DALYS lost to STH (Brooker, 2010).

Most worm infections are transmitted by contact with soil contaminated with worm eggs shed by infected humans via faeces. STH pass their eggs in faeces with most eggs requiring an incubation period in soil with adequate temperature, shade and humidity to become infective. After this they reach their human host through the penetration of skin (often feet) for hookworm, or through ingestion from contaminated hands or agricultural produce for *A. lumbricoides* and *T. trichiura*.

Helminth eggs can survive for prolonged periods in the environment. *A. lumbricoides* eggs have been shown to remain infective for several years in certain conditions so that the treatment of human waste is required before agricultural reuse (Katakura et al 1986).

Morbidity associated with intestinal helminth infections increases as the intensity of infections increases, intensity of infection being the number of actual worms harboured by an individual. The majority of the associated burden, particularly with hookworm, is understood to be in children of school age. A recent review of hookworm-related anaemia concluded that chronic and recurring hookworm infection throughout childbearing age can have a chronic effect on women's iron levels (Brooker et al 2008). This anaemia contributes to higher morbidity and mortality for both women and their children. Iron-deficiency anaemia is especially important in adolescent girls, and women of childbearing age with severe anaemia during pregnancy have a higher risk of low-weight births and an increased risk of foetal morbidity and mortality. Brooker and colleagues estimated that up to a third of pregnant women in sub-Saharan Africa are infected with hookworm and at risk of preventable hookworm-related anaemia (around 6.9 million women). In children, moderate to heavy infections with *A. lumbricoides* and *T. trichiura* may also result in malabsorption of nutrients and macronutrients, nutritional deficiency and growth retardation or failure (O'Lorcain and Holland, 2000). Moderate to heavy infections with any STH in children may also impair their cognitive development (Jukes et al. 2008, Stephenson et al. 2000). In severe cases of ascariasis, intestinal obstruction can occur, and an estimated 10,000 deaths per year could be attributed to this complication (de Silva et al. 1997).

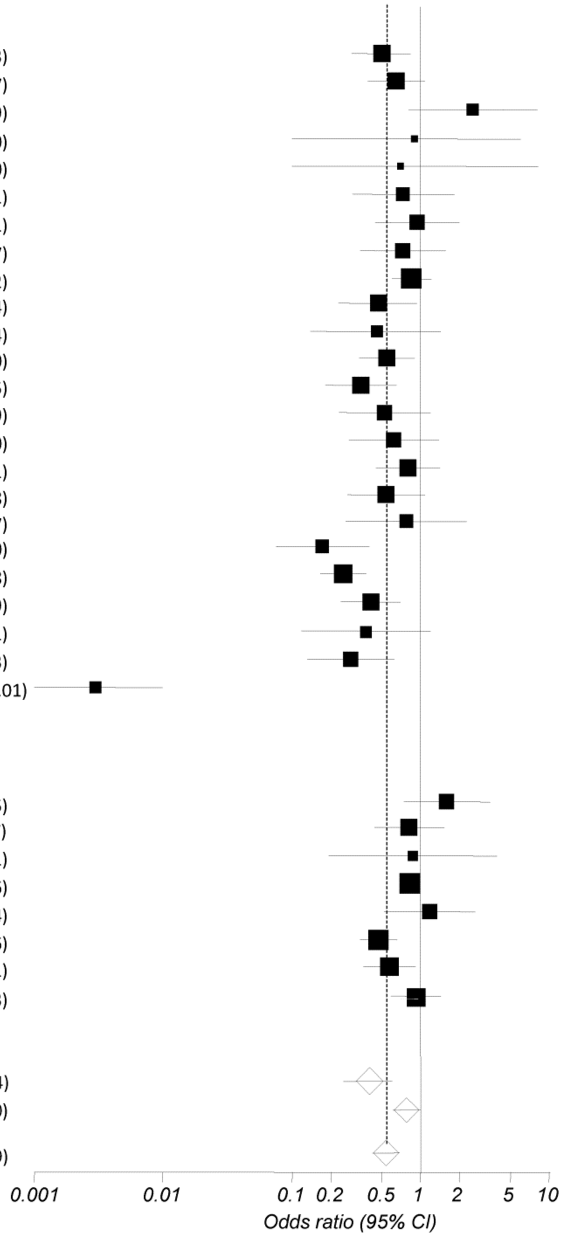
Current control efforts often focus primarily on mass drug administration (MDA). These drugs have been shown to be cost-effective but it remains challenging to sustain these campaigns over long periods of time. Treatment with drugs does not address the environmental transmission cycle, as evidenced by high re-infection rates, especially among the most at risk (Ziegelbauer et al 2012). In a recent systematic review by Jia and colleagues (2012), pre-treatment infection prevalence levels were observed 12 months after treatment for *A. lumbricoides* and *T. trichiura*, while for hookworm the 12 month re-infection rate was lower with 57% of the pre-treatment prevalence reached after 12 months (Jia et al, 2012).

Adequate sanitation offers the greatest potential to control STH infections as it prevents release of faeces into the environment thereby preventing transmission. Ziegelbauer and colleagues (2012) recently completed a systematic review for the effect of latrine availability and use on STH infections. They concluded that availability and use of latrines reduced the risk of combined STH infection by about 50% (fig. 6.3).

Figure 6.3: Meta-analysis examining the association of sanitation facilities with infection with the three common soil-transmitted helminths combined, extracted from Ziegelbauer et al (2012)

Ascaris lumbricoides

Source	No. infected/total no.		Odds ratio (95% CI)
	Toilet	No toilet	
Availability			
Al-Mekhlafi et al. [33]	N.A.	N.A.	0.50 (0.29, 0.83)
Asaolu et al. [52]	56/374	28/131	0.65 (0.39, 1.07)
Basualdo et al. [64]	4/50	15/454	2.55 (0.81, 7.99)
Corrales et al. [61][a]	N.A.	N.A.	0.90 (0.10, 6.00)
Corrales et al. [61][b]	N.A.	N.A.	0.70 (0.10, 8.20)
de Souza et al. [65]	18/361	7/105	0.74 (0.30, 1.81)
Ensink et al. [34]	22/1192	10/512	0.94 (0.44, 2.01)
Erlanger et al. [46]	16/29	238/380	0.73 (0.34, 1.57)
Gunawardena et al. [35]	120/237	131/240	0.85 (0.60, 1.22)
Hagel et al. [67]	80/145	34/42	0.47 (0.23, 0.94)
Holland et al. [60]	80/190	8/13	0.46 (0.14, 1.44)
Jombo et al. [54]	23/123	141/477	0.55 (0.33, 0.90)
Knopp et al. [58][c]	33/166	26/62	0.34 (0.18, 0.65)
Knopp et al. [58][d]	54/143	15/28	0.53 (0.23, 1.19)
Morales-Espinoza et al. [63]	N.A.	N.A.	0.62 (0.28, 1.40)
Olsen et al. [51]	27/90	50/143	0.80 (0.45, 1.41)
Stephenson et al. [49]	104/434	14/38	0.54 (0.27, 1.08)
Stothard et al. [56][c]	57/62	191/204	0.78 (0.28, 2.27)
Stothard et al. [56][d]	58/75	196/206	0.17 (0.08, 0.40)
Toma et al. [39]	35/245	162/407	0.25 (0.17, 0.38)
Torres et al. [66]	20/351	60/467	0.41 (0.24, 0.69)
Trang et al. [44]	169/795	5/12	0.38 (0.12, 1.21)
Trang et al. [45]	437/1057	22/31	0.29 (0.13, 0.63)
Ugbomoiko et al. [57]	33/176	231/234	0.003 (0.001, 0.01)
Usage			
Belo et al. [53]	N.A	N.A	1.59 (0.74, 3.45)
Ilechukwu et al. [59]	25/124	25/108	0.84 (0.45, 1.57)
Kightlinger et al. [50]	376/411	73/81	0.87 (0.20, 3.91)
Nguyen et al. [47]	497/1167	718/1511	0.82 (0.70, 0.96)
Nishiura et al. [37]	71/214	53/114	1.18 (0.53, 2.64)
Steinmann et al. [48]	53/350	213/777	0.47 (0.34, 0.66)
Traub et al. [40]	N.A.	N.A	0.57 (0.36, 0.91)
Wördemann et al. [62]	N.A	N.A	0.93 (0.59, 1.43)
Only availability (n=24)			0.46 (0.33, 0.64)
Only usage (n=8)			0.78 (0.60, 1.00)
Overall (n=32)			0.54 (0.43, 0.69)



Source: Ziegelbauer et al. 2012

A study in Salvador, Brazil, which compared neighbourhoods with storm water drains (to prevent seasonal flooding with sewage) or full water-borne sewerage with neighbourhoods that had neither found significant indirect effects (Moraes et al 2004). When the level of community sanitation was improved, the prevalence of *A. lumbricoides* infections reduced by 30 to 40%, *T. trichiura* infections by 20% and hookworm infections by over 60%, emphasising the importance of public transmission.

A recently published longitudinal cohort study of a city-wide sanitation programme in northeast Brazil reported reductions in the prevalence of helminth and protozoal infections in pre-school age children. *A. lumbricoides* was reduced by 42%, *T. trichiuria* infections were reduced by 62% (Barreto et al 2010).

Improved water supply and hygiene will have only a limited effect on hookworm infections, as infection occurs through contact with contaminated soil. Few studies have looked at the impact of improved water supply alone on *A. lumbricoides* and *T. trichiura* infections. Poor quality drinking water is an unlikely source of infection, as eggs tend to sink in water. However, improved water supply interventions in the USA and Saint-Lucia have respectively shown a 37% and 30% decreased risk of helminth infections in groups supplied with piped water and lavatories in households (Esrey, 1991). This effect was greater than for groups provided with a well in the courtyard (12%), suggesting that it is the quantity of water used that played a major role on *A. lumbricoides* and *T. trichiura* infections transmission control. Two intervention studies in which promotion of hand washing with soap after defecation or before meal as an intervention was compared with a control group remain inconclusive; as reported by Fung and Cairncross (2009), one such study showed a reduction in *A. lumbricoides* infections prevalence while another showed no impact on *A. lumbricoides infections* prevalence.

Conclusion: There is good evidence that lack of sanitation contributes critically to the burden of soil transmitted helminth infections and that improved sanitation can be effective in reducing infection. There is suggestive evidence that poor personal and domestic hygiene increases the risk of ascariasis and trichuriasis infections.

6.3.2 Trachoma

Not being able to wash and keep clean is also clearly associated with a wide range of skin infections and infestation with fleas, lice and mites, some of which are carriers of diseases such as typhus and plague.

Trachoma is a devastating disease common in hot and dry regions with inadequate hygiene. Trachoma is a bacterial infection of the eye; repeated infections cause damage to the cornea leading to blindness (Thylefors *et al.* 1995). Trachoma is a leading cause of preventable blindness worldwide (six million cases of blinding annually). Lack of hygiene and access to water is an important factor for trachoma transmission. *Musca sorbens* flies act as mechanical vectors of the disease, and their role is discussed later in this chapter in more detail. The lack of personal hygiene (most often due to the lack of adequate amounts of water) leads to child-to-child transmission of trachoma, and also cause trachoma-carrying flies to be attracted to unwashed faces, especially of children. Facial hygiene is part of the SAFE strategy to reduce trachoma (eyelid **S**urgery, **A**ntibiotic treatment, **F**acial cleanliness, and **E**nvironmental improvement, Emerson *et al.* 2004). It is estimated that more than 70% of trachoma incidence is caused by *M. sorbens* flies that breed in scattered human faeces (Emerson *et al.* 2004; Montgomery & Bartram 2010).

There have been a number of systematic reviews conducted to address the four SAFE components (see Table 6.1) and there is sufficient evidence for all components of the SAFE strategy to justify its urgent implementation in trachoma endemic regions as a means of preventing and treating this disease.

Table 6.1 Reviews assessing different SAFE and WASH component interventions

Review	S	A	F	E
	Non-WASH		WASH	
Evans et al, 2011				
Hu et al, 2010				
Rabiu et al, 2007				
Ejere et al, 2007				
Yorston et al, 2006				
Pruss & Mariotti, 2000				
Emerson et al, 2000				

Source: (Cumming *et al.* 2012)

Conclusion: There is suggestive evidence that ending open defecation and promoting sanitation is an efficient way to reduce trachoma transmission by reducing fly breeding sites and therefore reducing the number of (M. Sorbens) flies involved in the transmission. There is some evidence that hygiene promotion is effective in preventing active trachoma in endemic settings but sustainable changes in hygiene behaviours may be difficult to achieve. The evidence on improved water supply to control trachoma in endemic settings is mixed.

6.3.3 Schistosomiasis and Guinea worm

Schistosomiasis and Guinea worm are both caused by worms that spend some time in an aquatic host before they are transmitted to the next human host, and are therefore associated with water bodies.

Schistosomiasis (bilharzia) is the most common of these. Its transmission is complex, involving human faeces and urine, fresh water snails as intermediate hosts and contact with water as the cause of infection. Schistosomiasis can cause chronic and often irreversible liver and kidney failure. Around 190 million people are infected worldwide, 280,000 die annually and many others suffer from chronic illness.
The majority of efforts to control schistosomiasis are through MDA and control of snails population although interventions to reduce contact with contaminated water (e.g. by providing a safe water source near the home) have the potential to reduce transmission substantially (Gryseels et al. 2006). These interventions can only be effective though if the safe water supply is used exclusively and for all domestic needs. From four studies deemed rigorous on the effect of providing water supply and washing facilities, Esrey and colleagues (1991) concluded that the median reduction in schistosomiasis morbidity reached 77%. A similar figure was found in a study evaluating the impact of water and sanitation interventions combined.

Guinea worm (dracunculiasis) is transmitted through ingestion of drinking water contaminated with larvae from the sores of infectious individuals. The larva makes its way to tissues under the skin, where it grows slowly. After about a year, it emerges through an ulcer that forms in the skin. Traditional techniques to remove the worm include rolling it slowly around a matchstick. Doing this is extremely painful and there is a risk that the worm will come into contact with water, starting the cycle all over again. Guinea worm is becoming increasingly rare with less than 2,000 cases worldwide (CDC 2011) annually as the eradication campaign nears its conclusion. This success built on an integrated approach combining case management, prevention of cases' contact with surface water and safe water provision. Safe water supply interventions reduced annual incidence up to 98% in particular settings (Cairncross & Tayeh 2002).

Conclusion: *There is suggestive evidence that lack of access to protected sources of water close to home increases the risk of exposure to schistosomiasis infested water bodies and the risk of infection with schistosomiasis. Whilst Guinea worm is nearing eradication, WASH is acknowledged as having played an important part in achieving this.*

6.4 Insect-borne diseases

6.4.1 Mosquito-borne diseases

In order to complete the mosquito lifecycle, female mosquitoes require water for oviposition. As a result mosquito larvae have been retrieved from septic tanks, wet pit latrines, storm water and sewage drains, and wastewater treatment plants (Mukhtar et al. 2006; Castro et al. 2010; Curtis & Hawkins 1982). Mosquitoes do not breed in dry forms of sanitation, or pit latrines without water (Curtis & Hawkins 1982). Anopheles mosquitoes, unlike culex mosquitoes, do not tolerate the low levels of dissolved oxygen, and increased levels of nutrients and salts that tend to be found in wastewater. They are normally only found in sanitation facilities with reasonably clean water, though in the absence of clean water sources they will also breed in sewage (Mukhtar 2006).

The main mosquito-borne disease linked to sanitation is lymphatic filariasis, spread by Culex quinquefasciatus – a mosquito which prefers to breed in septic tanks, pit latrines and wastewater drains. Lymphatic is a complex infection of human lymph vessels which leads to poor lymph drainage, especially in the lower extremities with often gross swelling and disfiguring oedema at affected body parts, including legs and scrotum (Taylor et al. 2010).

A reason often mentioned by people practising open defecation is that a latrine visit will result in being bitten by flies and mosquitoes that use the sheltered, warm, humid and dark conditions of the pit latrine to breed and mature. The application of a floating layer of expanded polystyrene beads to the latrine pit contents can reduce mosquito breeding effectively to zero (Curtis & Minjas 1985) and help reduce the prevalence of lymphatic filariasis if applied on a neighborhood or city-wide scale (Maxwell et al. 1999). The intervention was found to be sustainable as the beads float automatically to the top of a pit when water builds up in the latrine. It is also easy to apply, well received by latrine owners and cheap (Curtis 2005). It has, however, still not been applied on a city-wide basis and the trials with polystyrene beads, started in Tanzania in the 1990s, have not been continued by the local municipality, and therefore the long-term sustainability of the method is unclear.

The centralised collection of urban sewage will generate large amounts of wastewater and the need for treatment to guarantee safe disposal into the environment or use in agriculture. A wide variety of wastewater treatment technologies exist that can remove almost all pathogens, heavy metals and nutrients that are normally found in wastewater. However, most of these wastewater treatment technologies are expensive or require a reliable electricity supply. As a result, the most commonly recommended form of wastewater treatment technology for a low-income country is a system of wastewater stabilisation ponds (WSP) (Mara 2000, Ensink 2007). These consist of a system of shallow ponds, in which wastewater is treated through sedimentation and biological processes. A well-designed system of WSP consists of anaerobic, facultative and maturation ponds in a series in which wastewater will be treated for a period between 15 and 20 days.

The downside of WSP is that they create large bodies of open water close to urban centres, thereby creating possible breeding sites for disease-transmitting mosquitoes. Limited attention has been paid to the potential role of WSP in the generation of vector mosquitoes. A study in Nigeria found that living within 300 meters of a WSP was associated with an increased risk of malaria (Agunwamba 2001), while work in Pakistan found massive mosquito breeding all year round (Mukhtar *et al.* 2006). The anaerobic ponds were found to generate predominantly *Culex spp*, while the facultative and maturation ponds were found to be positive for *Anopheles spp* (Mukhtar *et al.* 2006). Mosquito breeding was associated with poor maintenance and grass growing at the edges of the ponds. The removal of emergent grasses and reinstallation of grids resulted in the near complete removal of mosquito breeding (Mukhtar *et al.* 2006).

Lack of a reliable water source close to home requires householders to store water in large quantities at home. The mosquito species that transmit dengue fever (mainly *Aedes aegypti*) have been shown to breed preferentially in storage containers. Dengue fever is a very common viral infection especially in Southeast Asia, South Asia and Latin America. It can lead to internal bleeding, shock and death. *A. aegypti can* reach high numbers even in dense urban areas (Mammen 2008). A cohort study from Vietnam recently found strong evidence that dengue fever is most common in areas without piped-in water supply (Schmidt *et al.* 2011).

Conclusion: There is good evidence that poorly constructed latrines increase mosquito vectors that transmit lymphatic filariasis. There is suggestive evidence that an inadequate water supply increases the risk of dengue fever.

6.4.2 Other insect-borne diseases

Flies, cockroaches, and mosquitoes all thrive in the absence of sanitation, or when sanitation is poorly managed. Unhygienic sanitation provides insects with a stable supply of food and breeding sites. Whilst some insects can be effective vectors for different excreta-related diseases, the majority that are linked to inadequate sanitation do not pose a direct health risk, though they often are a source of considerable nuisance. The presence of flies, cockroaches and mosquitoes in large numbers in latrines, drains and septic tanks may deter people from using, maintaining and cleaning these facilities. Apart from flies, inadequate water and sanitation can increase the abundance of other disease-transmitting insects, especially mosquitoes.

Houseflies live in close proximity to humans, and have been associated with different infectious diseases because of their breeding and feeding preferences. Female flies prefer to lay their eggs in organic material, including human excreta, garbage and manure. Male and female flies will feed on all human food, garbage, manure and human sweat. Due to their frequent contact with water, food and human excreta, flies can act as effective mechanical vectors for different pathogens.

Flies are an important, though often ignored, vector of diarrhoeal disease. The common house fly has been found to carry a wide-diversity of enteric pathogens including Vibrio cholerae (Fotedar 2001), Shigella spp (Khin et al. 1989), Salmonella spp (Khin et al. 1989), Cryptosporidium parvum and Giardia lamblia (Szostakowska, 2004). A study investigating fly density and diversity in, and around, rural households in Thailand found the common house fly to represent roughly 90% of all flies caught, with the number of flies collected in kitchens as high as 80 per 30 seconds (Echeverria et al. 1983). The density of flies showed a strong increase during the hottest and driest months of the year, which coincided with the main diarrhoea transmission season. Pooled flies collected from kitchens were found in 68% of samples to be positive for E. coli, while Shigella flexneri and non-O1 Vibrio cholerae were detected on 6% of all fly pools (Echeverria et al. 1983).

Fly control, through the use of yeast-baited fly traps, was found in Israeli army camps to reduce fly densities by 64%, and overall diarrhoea prevalence in soldiers was reduced by 42%, while shigellosis specifically was reduced by 85% (Cohen et al. 1991). The use of flytraps in the North West Frontier Province of Pakistan seemed to have limited impact on fly densities, but spraying of households with an insecticide was found to have almost completely eliminated fly populations and sprayed villages were reporting a 23% reduction in diarrhoea incidence (Chavasse et al. 1999). An independently conducted study in the same year in the Gambia reported a similar impact of spraying villages with the insecticide deltamethrin and showed a reduction of 57% to 71% in domestic fly (Musca domestica) populations and a 22% and 26% reduction in diarrhoea prevalence in the wet and dry season respectively, though the reduction in the dry season was found to be non-significant as a result of the general low diarrhoea prevalence in the dry season (Emerson et al. 1999).

Pit latrines and septic tanks have been found to be major breeding sites for flies (Curtis & Hawkins 1982), though the factors regarding design, use and decomposition processes that might be associated with fly breeding are still not well known. Pit latrine design, such as the introduction of concrete slabs, water seals, and ventilation pipes with fly screens, could reduce fly breeding considerably, though the introduction of ventilated improved pit (VIP) latrines in the Gambia had no impact on the number of house flies collected from children's faces (Emerson et al. 2004).

Conclusion: There is suggestive evidence that inadequate sanitation and hygiene promotes the abundance of those flies that may increase the risk of diarrhoea.

6.5 Chemical contamination of water - arsenicosis and fluorosis

While much of the health impact of water improvements is likely due to reductions in the transmission of infectious diseases, in a number of geographic regions, poor chemical drinking water quality is associated with a substantial health burden. This chemical contamination may be the focus for specific interventions, but can also limit the available options for safe water supply. The results of systematic searches for high quality studies for the effect of WASH on arsenicosis are included in annex 2. No such studies were identified for the impact of WASH interventions on fluorosis, which reflects the scarce attention that was paid to this issue.

Globally, arsenic contamination of groundwater is estimated to be responsible for both substantial morbidity and mortality (Fewtrell *et al* 2005b; Smith *et al* 2009; Sohel *et al* 2009; Argos *et al* 2010) through a wide range of systemic health problems.

One of the most direct health effects of arsenic exposure is skin lesions which can create substantial morbidity (Fewtrell *et al* 2005a). In addition, there is good evidence for the effect of high levels of exposure to arsenic in drinking water on lung and bladder cancers (Celik *et al* 2008; Marshall *et al* 2007; Chen & Ahsan 2004; Luster & Simeonova 2004; Ferreccio & Sancha 2006; Kapaj *et al* 2006; Rahman *et al* 2009). In spite of the methodological limitations of many of the contributing ecological and case-control studies, several reviews found evidence of increased risk in areas with high levels of arsenic exposure.

There is also strong evidence that exposure to high levels of arsenic in drinking water is associated with increased risk of developing type 2 diabetes (Diaz-Villasenor *et al* 2007; Del Razo *et al* 2011) and cerebrovascular disease (Cheng *et al* 2010;Meliker *et al* 2007; Wang *et al* 2007, Yuan *et al* 2007). Exposure to arsenic during pregnancy is also associated with higher rates of fetal loss and infant death (Sohel *et al* 2010) and exposure to arsenic in utero and in early childhood is associated with lung cancer and bronchiectasis in young adults (Smith *et al* 2006). Exposure in childhood also has an impact on cognitive development (Wasserman *et al* 2007; Wasserman *et al* 2004).

A range of intervention strategies are used to reduce the disease burden associated with arsenic including information campaigns, provision of alternative water sources and treatment of contaminated water.

A recent systematic review for providing information (Lucas et al 2011) found some evidence for the effect on use of alternative water sources, although overall the results were considered equivocal. The review examined information dissemination in the context of both arsenic and faecal contamination.

The second general approach is the provision of alternative water sources, such as groundwater from chemically safe geological layers, or treated surface water or rainwater harvesting. Some evidence shows that mitigation efforts have led to reductions in arsenic exposure (Chen *et al* 2007). However, Gardner and colleagues recently found that intensive arsenic mitigation efforts through well switching did not succeed in reducing the exposure to arsenic in a cohort of pregnant women and their offspring followed up for seven years (Gardner *et al.* 2011). Other sources of arsenic contamination, especially food, should be considered (Williams *et al* 2006).

However, switching to alternative sources creates a risk that households will end up consuming water with higher levels of microbial contamination, thus trading one health risk for another (Lokuge *et al* 2004). In a modelling study, Howard and colleagues found that the provision of deep tube wells was less likely to result in an unintended increase in disease through microbial contamination and resulted in the most effective strategy in terms of overall risk reduction (Howard *et al* 2006; Howard *et al* 2007). In Bangladesh, Escamilla and colleagues measured a significant decreased risk of diarrhoea in children under five in households who had switched to a deep tube well instead of switching to a shallow tube well (Escamilla *et al* 2011). However, Wu and colleagues measured an increased risk of childhood diarrhoea up to 26% in households using low-arsenic levels shallow wells instead of arsenic contaminated shallow wells (Wu *et al* 2011).

Finally, a number of approaches have been developed for treating arsenic contaminated water either at the source or at the point of use (Bissen *et al* 2003). Some of these rely on iron and aluminium-based adsorption to remove dissolved arsenic (Giles *et al* 2011) while others rely on physical removal through membrane filtration (Holl 2010), or coagulation (Norton *et al* 2009). Whilst these approaches have been shown to be efficacious, and as with other WASH interventions, there are concerns around the sustainability of behaviours and the appropriate processing of waste (Giles *et al.* 2011; Sullivan *et al.* 2010; Milton *et al.* 2007).Costs of arsenic removal are quite high, especially if users are expected to cover all running costs including replacement of chemicals or saturated media (Johnston *et al* 2010).

A wide range of efforts have been made to document and map arsenic contamination levels in regions with high natural levels. However, there is also a need to continue to investigate the dynamics affecting arsenic movement and change over time, in order to plan mitigation approaches (Fendorf *et al* 2010). Additional research on arsenic groundwater contamination dynamics, along with modeling the potential impact of alternative strategies on arsenic and microbial disease burden could help prioritise investment strategies in arsenic endemic areas.

There is strong evidence for the disease burden associated with arsenic exposure in drinking water, including cancers, metabolic, cerebrovascular, and cardiovascular disease. Provision of alternative sources with minimal risk of microbial contamination provides the best long-term option for reducing this disease burden and a careful targeting of the populations most exposed to arsenic contamination can ensure that the potential increase in childhood diarrhoea does not counterbalance the positive effects of arsenic mitigation on the total health burden.

High levels of fluoride naturally occur in a range of geographic areas including India, Turkey, South America and elsewhere (Paoloni *et al* 2003; Armienta & Segovia, 2008; Jain *et al* 2010; Wavde & Arjun 2010; Baba & Tayfur 2011; Brindha *et al* 2011; Suthar 2011). Excessive fluoride is associated with dental, skeletal and joint disorders (NRC 1999, Ozsvath 2009). Fewtrell and colleagues attempted to estimate the global burden of disease associated with fluoride in drinking water (Fewtrell *et al* 2006). They concluded that the burden is likely to be considerable in specific countries and regions. However, there is inadequate data available to reliably estimate the burden. As with arsenic exposure, there is likely to be an additional health burden associated with the need to seek alternative sources, but this burden has not been estimated. Additional data are needed on exposure and burden of disease in order to appropriately prioritise fluoride contamination.

Fluoride removal is less studied than arsenic removal, but operates along the same physical principles. Fluoride removal is often more costly than arsenic removal, since milligrams, not micrograms, of contaminant must be removed, leading to more frequent media saturation (Feenstra, 2007).

While arsenic and fluoride are the most common chemical contaminants, most studies of the effects look at each chemical independently. There is a potential that the two will have synergies that may increase the actual health burden, however this is as yet underexplored (Chouhan & Flora 2010).

Conclusion: There is good evidence that, in some regions, drinking water sources contaminated with arsenic and fluoride are associated with a large disease burden (including cancers, metabolic, cerebrovascular, and cardiovascular diseases). There is suggestive evidence that changing water sources may reduce the risk of arsenicosis but there is no evidence available for the efficacy of interventions to address fluorosis.

7. Non-health impacts of WASH

Decisions on how best to allocate resources between different public health interventions should not exclusively be based on their effect on health alone. Two further criteria, (1) the risk of adverse effects, and (2) the potential for non-health benefits, need to be taken into account, especially since these factors strongly influence acceptability of, and compliance with, interventions by the target population and policy-makers (Ross *et al.* 2006).

For example, clinical approaches to infectious disease control are not promising in this regard. Although the risks of adverse effects may not be very large, there is always the risk that, clinical interventions such as the supplementation of micronutrients are only beneficial to certain populations and detrimental to others. Further, clinical solutions are rarely associated with benefits other than treating or preventing the disease in question.

This stands in contrast especially to improving water and sanitation, both of which have the potential to benefit poor populations in a variety of ways, as outlined in the following paragraphs (UN Water 2008). Water, sanitation and hygiene interventions also do not commonly have a substantial high risk of adverse outcomes.

It is not always easy to separate health from non-health benefits as most non-health benefits may eventually lead to health benefits and vice versa. This is especially the case for educational achievements. Therefore the following section will necessarily make cross references to health benefits.

7.1 The impacts of WASH extend beyond health

Water supply offers enormous benefits in terms of saving time and drudgery spent carrying water home. In urban centres, and in some rural environments, poor people pay water vendors for bringing water closer to their homes. Typically they pay 10 to 15 times the price of water itself; they are not paying for the water, but for its delivery. This shows that their time has a monetary value.

A study by Whittington *et al.* (1989) compared the price paid to vendors for water by households in rural Kenya with the water-fetching time this saved them to obtain an implicit valuation of their time. In most cases, the result was close to the unskilled wage rate; a reasonable estimate of the opportunity cost of someone’s time. Another example of the monetary value of poor people's time is provided by Aiga & Umenai (2002) in Manila, Philippines, where families benefiting from water supply no longer needed to queue for water, or to buy it from vendors. The result was that household incomes doubled. The amounts of money involved, and hence the scale of the benefit, are substantial. Whittington (1991) found that in Onitsha, Nigeria, the size of the vendor market was larger than the total revenue of the water utility.

As a proportion of household income, the payments are also large. In a multi-country study, Zaroff & Okun (1984) found that the median proportion was 20% of household income. In a poor household’s budget, according to Engel’s law, the only item large enough to sacrifice for this expenditure is food. Providing water more cheaply than the vendors will therefore offer a nutritional benefit to the poorest families.

Economists agree that the consumer surplus should be included in project appraisal. Since the price elasticity of demand is almost negligible (Cairncross & Kinnear 1992) right up to half of a household's income, the value of water appropriate for *ex ante* appraisal of water supply projects is many times the price which the utility proposes to charge for it.

Some economists have argued that the *primary* benefits from water supply are not those related to health but from factors such as timesaving alone. For instance, in the late 1980s, a group of World Bank economists spent six months devising a new rural water policy (Churchill *et al.* 1987). Their conclusion was that based on the estimates of costs in a variety of contexts in developing countries and estimates of the value of time saved, water supply investments could be justified on the basis of timesaving alone, even up to the level of household connections. They concluded that there were no health benefits – although they were not public health professionals – and if any did accrue these were no more than additional unintended benefits.

Sanitation too is about far more than health. When a latrine-owning household in the developing world is asked why they made the investment and what they like about it, “health” is usually at the bottom of the list, be it a short list of four options in the Philippines (Cairncross 1992), or a list of more than 30 in rural Benin (Jenkins & Sugden 2006). The higher priorities include comfort, convenience, security and the social status conferred by ownership of a latrine.

The implication for policy is that people are willing to pay for sanitation, although not primarily for health reasons. Sanitation agencies can take advantage of this by marketing sanitation and keeping subsidies down to ensure that every latrine is paid for and, therefore, wanted.

This story is slightly different regarding hygiene promotion and household water treatment, for which the primary benefit is health (Schmidt & Cairncross 2009). In spite of that fact, health is not the most effective driver in persuading people to practice hygienic behaviour such as washing their hands with soap. Emotional drives, such as sex appeal or the desire to nurture children, are more powerful (Curtis *et al.* 2009). If such promotion programmes are successful, they will generate substantial revenue for the manufacturers of soap and water treatment devices. An unstated (and unrealised) objective of the global campaign to promote handwashing with soap is to persuade the world's major soap manufacturers that funding the campaign is worth their while. If they could be persuaded of that, hygiene promotion could be self-sustaining.

7.2 WASH and education

A good example of potential non-health benefits of sanitation is school sanitation in low-income settings (Adams *et al.* 2009). School sanitation is unlikely to be associated with major adverse effects but, in addition to contributing to the control of diarrhoea, helminths, and trachoma, it may encourage school attendance, especially of girls. The effect of girls’ menstrual management in low-income countries is frequently cited in discussions on how to improve development outcomes for girls and women (IRC 2007, 2009a, 2009b).

A recent DFID-funded systematic review (Birdthistle *et al.* 2011) found that there is currently no evidence in the peer-reviewed literature for, or against the hypothesis that well-maintained separate toilets for girls may increase school enrolment and attendance for girls

– even after they reach menarche. More research is needed in this area. There is a lack of studies investigating the impact of sanitation on the attendance and performance of girls in school and there is therefore a need for more research.

Further, children being habituated to adequate sanitation in schools may later in life increase demand for sanitation in the community as a whole. School sanitation creates educational opportunities to promote safe environments at home and in the community. Healthy children in healthy environments learn more effectively.

Combining health and non-health benefits, WHO has estimated that 1,863 million schooldays would be gained due to less diarhoeal illness if everyone in the world had access to a regular piped water supply and sewage connection in their house (WHO 2004). Some of the most severe consequences of chronic worm infections are those related to education, and intellectual achievement. Children enduring intense infections with whipworm miss twice as many school days as their infection-free peers (WHO 2005). While children with heavy-intensity hookworm infections have shown to suffer from growth retardation, as well as intellectual and cognitive impairments. As a result, the hookworm has been associated with impaired learning, increased absences from school, and decreased future economic productivity (Miguel & Kremer 2004).

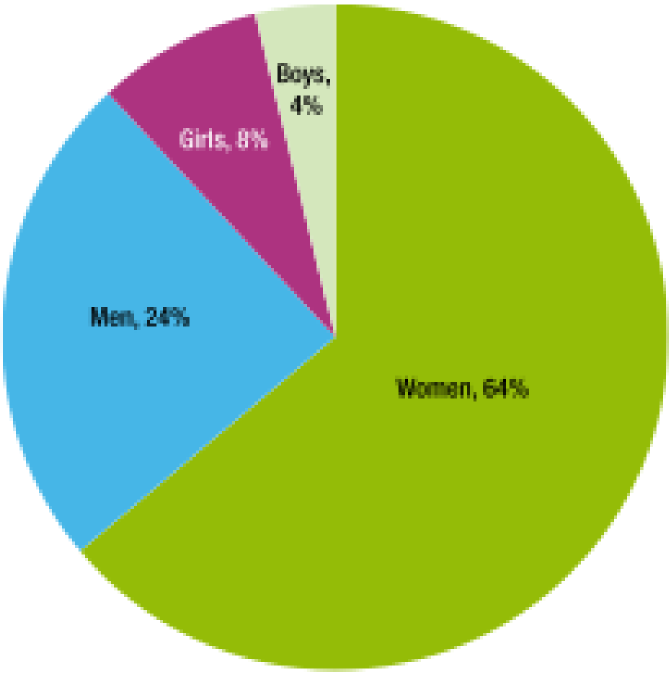
Improved education encourages economic activities in the long term, but water and sanitation also have direct economic effects, especially time savings. Contrary to widespread belief in the health sector, the undoubted benefits to health are not normally foremost in the minds of those provided with new water supplies. A study of the economics of rural water supply by the World Bank concluded that, "The most important benefit of rural water supply improvements from the perspective of the people affected is generally the fact that water is brought closer to where they live…There is no indication that rural populations expect health gains" (Churchill *et al.* 1987).

In general, however, it is difficult to measure precisely the impact of WASH interventions on education, because such studies would have to be conducted over a long period of time and because most WASH interventions are complex, the evidence base is still incomplete. Currently ongoing large sanitation trials in Kenya and India may shed more light on this important issue in the future.

7.3 WASH and gender

There is a considerable amount of literature on water and gender, though very little of this reaches into substantive discussions about sanitation (special issue of Gender and Development, 2010). The discussions about water emphasise women's primary responsibility for caring for the household, and their major role in addressing deficiencies in access to water. In Africa alone, people spend 40 billion hours every year just walking for water. Women and children usually bear this burden (WHO/UNICEF JMP 2004). Figure 7.1, using data from household data from 45 countries, shows that women carry two thirds of the burden in drinking-water collection (WHO/UNICEF JMP 2010).

Figure 7.1 Distribution of household members who usually collect water



Source: WHO/UNICEF JMP 2010

There is relatively little discussion about how women, in this caring (reproductive) role, manage without sanitation facilities, or about how responses are managed either at the community or individual level. Inadequate toilet provision - especially in low-income urban settlements - raises three particular issues: women's concerns about the availability of the services and lack of hygiene which does not enable them to behave in a way that satisfies their self-respect and social reputation (i.e. not to be seen in public going to the toilet in day time); immediate physical safety for themselves and their children; and the social stigma attached to living in a low-income settlement that is without adequate services (Amnesty International 2010).

A study in Pakistan found that inadequate water, sanitation and other services were major causes of the large gender gap between boys and girls, in part due the inequitable effect on chores (Holmes 2006). As outlined above, having clean toilets in schools may improve the attendance rates of adolescent girls. A World Bank study in four countries showed that girl's school attendance increased significantly for every hour reduction in water collection. In Nepal, attendance improved by over 30% (Koolwal & van de Walle 2010).

An important argument for easy access to water can be made on economic grounds alone. The saving in time and drudgery carrying water home from the source is substantial, and there are several reasons to attribute a monetary value to it. The idea that poor women's time is of little value ignores the opportunities for income generation by petty trading and handicrafts, through which they can contribute significantly to GNP and welfare if their time allows. If time saved for women from water carrying is spent, not in income generation but in childcare or leisure, that is evidence that they value those pursuits more highly.

The most powerful argument for the monetary value of poor women's time is that households often pay others to deliver their water, or pay to collect from nearby rather than use more distant sources which are free of charge. The prices charged by water vendors are typically more than ten times, and can be up to 50 times, the normal tariff charged by the formal water supply utility. Since the poorest urban households typically spend more than 90% of their household budget on food, the money they spend on water must be sacrificed mainly from their food budget (Cairncross & Kinnear 1992).

Some idea of the transformation in the quality of life, particularly of women, which accompanies provision of a water supply to a poor community, can be had from a retrospective evaluation of completed projects carried out in four countries by WaterAid using Participatory Rapid Appraisal (PRA) methods (Cairncross & Valdmanis 2006). The principal benefits volunteered by local communities as stemming noticeably from water supply projects completed several years previously are shown in Table 7.1. A number of them were emphasised by beneficiary communities in all four countries. As already shown in the section on education above, improving water access is beneficial especially for girls and women, and therefore has the potential to contribute to gender equality.

Table 7.1 Benefits of rural water supply, mentioned spontaneously by local communities in the course of a participatory evaluation in four countries, 2000

	Ethiopia	Ghana	India	Tanzania
Less tension/conflict		X	X	X
Community unity			X	X
Self-esteem (e.g. of schoolchildren)	X	X	X	X
Women's empowerment	X	X	X	X
Women's hygiene (e.g. menstrual)	X			X
Family quality time	X	X		X
Improved school attendance	X	X	X	X
Teachers accept posting to village		X		

Source: Adugna *et al.* 2001

7.4. WASH and poverty

There is good evidence that access to WASH services is beneficial in reducing poverty and that poverty and the adverse consequence of WASH are closely related as discussed in section 4.2. In Brazil, Monteiro *et al.* (2010) used a series of household surveys between 1974 and 2007 to examine the trends and disparities in childhood stunting. In addition to finding a decline in stunting, they found that improved water and sanitation was partially responsible for reductions in the disparity between children in poor and better off households. Lack of access to these basic services translates into real economic losses. In

analysing historical data on child mortality from Stockholm (1878 to 1925), Burström *et al.* (2005) also found that improved water and sanitation were essential in reducing disparities in child mortality.
Poor access to sanitation is likely to cause greater problems in poor households and communities than rich ones. In Mexico, Stevens and colleagues (2008) found that poor sanitation accounted for over 6% of child mortality in the poorest 20% of households and less than 1% in the richest 20%. Agha (2000) found that poor sanitation and water were partially responsible for slow progress in reducing infant mortality among poor households in Pakistan during the 1980s and early 1990s.

There is more discussion of this in section 9 on the economic burden associated with unsafe WASH.

Conclusion: Most of the available evidence on the effect of WASH on education and gender is based on circumstantial evidence and small observational studies, and statistically appears weak. Further studies are needed to explore non-health benefits of WASH. Nevertheless, what little direct evidence exists confirms the view that non-health benefits of WASH interventions are substantial and critically contribute to the economic benefit as well as acceptability of interventions. Only by including such non-health benefits can the true benefit of WASH interventions be adequately judged.

8. WASH interventions

8.1. Description of interventions (quantity, quality, sanitation and hygiene)

The components interventions of WASH are described in the following sections

8.1.1 Water quantity improvements
8.1.2 Water quality improvements
8.1.3 Sanitation, in particular proper disposal of excreta
8.1.4 Hygiene, including personal hygiene, domestic hygiene, and hygiene promotion.

These interventions, when carried out effectively, have the potential to disrupt pathogen transmission, improve the physical and chemical parameters of water quality and reduce disease burden. These interventions will be discussed here.
These four 'interventions' mask a diverse range of technologies and approaches.

8.1.1 Water quantity interventions

A secure and sustainable water supply improves both water quality and water access, and thus water quantity. In practice the water from a well or a constructed water supply will be of better quality than water from a traditional source. For example, a water supply using groundwater will be of better biological quality than surface source, and lining the well will also improve quality. The quantity of water used, however, will increase in a conditional relationship with the convenience of the water source. If the old source is more than a kilometre away from the home, a more convenient source will lead to increased water usage. If the new source is in the home or in the yard, consumption will double or treble, but within the range of up to 1 km, the distance to a public water source makes very little difference to water consumption (see Figure 5.2). The provision of an improved public water source when the old source was within a kilometre is unlikely to lead to substantial health benefits however good the water quality may be.

In Burkina Faso, a tapstand in the yard resulted in a threefold increase in hygienic behaviours by mothers over mothers using wells outside the compound and a twofold increase in hygienic behaviours over mothers who used either public standpipes or wells within the yard (Curtis *et al.* 1995).

Studies that assessed the impact of water quantity improvements on diarrhoea morbidity found median disease reductions ranging from 20-25% (Esrey *et al.* 1985 & 1991, Fewtrell *et al.* 2005a, Waddington *et al.* 2009).

Because of the relationship between level of water supply service and water consumption, house connections are associated with particularly large reductions in endemic diarrhoeal disease (Esrey & Habicht 1986, Esrey 1991). They also have two other advantages; first, they offer the greatest time-saving benefits, second, cost recovery is easier than from public taps because those who default can have their connections shut off until they pay.

Conclusion: Biological plausibility, circumstantial evidence and range of observational studies show that increasing access to sufficient quantities of water can contribute critically to health. However, there are no high quality randomised

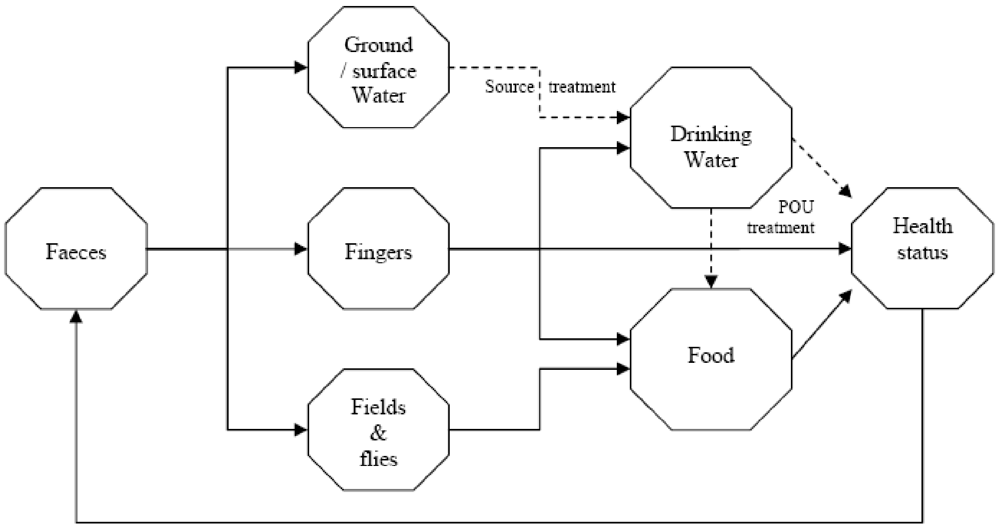
controlled trials and consequently it is not easy to quantify the effect. Overall, the evidence can only be regarded as suggestive.

8.1.2 Water quality interventions

Water treatment, both in the household and at the source of the supply, are options for improving water quality; interventions to treat and maintain the quality of water at the point of use (POU) are considered to be among the most effective water quality interventions (Clasen *et al.* 2007). However, POU water treatment offers only the health benefit and so its choice as an intervention depends purely on the epidemiological evidence. Problems with that evidence are discussed in Section 1 and elsewhere. Further research is needed to establish whether POU water treatment is a worthwhile public health intervention to take to scale.

Water quality interventions relating to chemical quality are discussed above in section 6.8.

Figure 8.1 – Water quality barriers to faecal-oral disease transmission



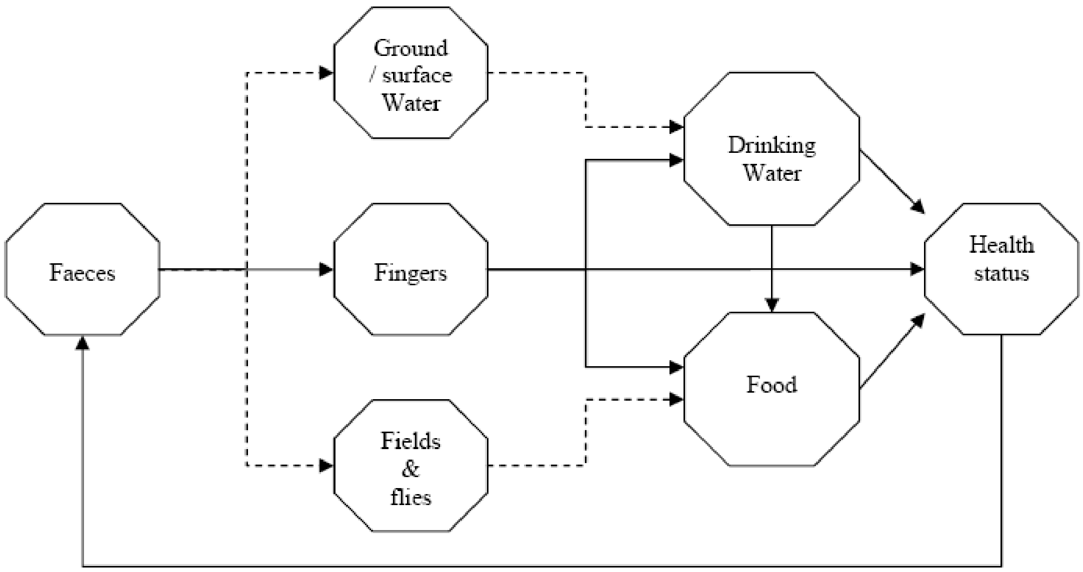
Source: Waddington *et al.* 2009

Conclusion: There is suggestive evidence from randomised controlled trials that improving water quality at the source and in the home can reduce diarrhoeal diseases. Household water treatment is one of the very few WASH interventions that under certain circumstances can be tested in a blinded randomised trial. Several blinded trials are currently underway and will hopefully shed light on this issue in the near future.

8.1.3 Sanitation

By removing contact with excreta, sanitation technologies eliminate one of the main transmission routes of diarrhoeal pathogens (as illustrated by Figure 8.2). By removing a transmission pathway, it is possible to reduce the morbidity and mortality associated with diarrhoeal disease. Reviews of studies conducted on the impact of proper excreta disposal on health found that sanitation improvements reduce diarrhoea morbidity by 22-36% (Esrey *et al.* 1985 & 1991, Waddington *et al.* 2009).

Figure 8.2 – Sanitation barriers to faecal-oral disease transmission



Source: Waddington *et al.* 2009

With sanitation as with water supply, there is a wide range of possible levels of service, from "cat sanitation" (in which the user carries a hoe to the defecation site and buries their faeces on the spot) to flush toilets with sewerage. The Joint Monitoring Programme (JMP) categorises the following as "improved" means of sanitation: flush toilets, piped sewer systems, septic tanks, flush/pour flush pit latrine, ventilated improved pit latrine (VIP), pit latrine with slab, and composting toilets. According to the JMP, other forms of sanitation, such as pit latrines without slabs, may not adequately protect individuals or the environment from contamination. However, unlike water supply, there is no firm evidence of differential health benefits between different levels of service or different sanitation technologies (Norman *et al.* 2010). It may also be that sanitation is more effective in dense urban settings than in rural areas.

A second difference is that the benefit accrues to the community and not the individual. In economic terms, there are externalities. To express it another way, my latrine protects my neighbours from my faeces more than it protects me.

A third difference from water supply is that the provision of sanitation facilities does not guarantee that they will be used or used reliably or by every member of the household. To ensure that facilities are used, sanitation *promotion* is an essential part of any sanitation programme. It can also be combined with hygiene promotion.

A Cochrane Review found that introducing or expanding the number and use of latrines or other facilities was protective against diarrhoea (Clasen *et al.* 2010). However, the authors could not estimate with precision the protective effect of sanitation against diarrhoea due to heterogeneity of the sanitation interventions in the studies reviewed. The authors called for more rigorous studies, including randomised controlled trials, to provide better evidence on the impact of the **disposal of human excreta for preventing diarrhoea.**

Conclusion: The biological plausibility of sanitation contributing substantially to reducing a range of WASH related infections is very high, but due to methodological issues the evidence from intervention studies is suggestive only. Several currently

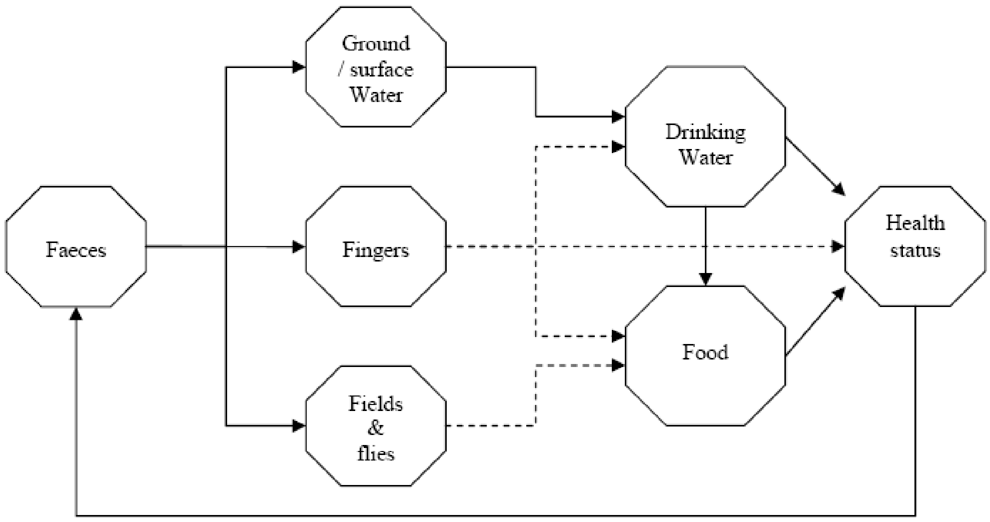
ongoing sanitation trials are likely to critically improve the evidence base in the next few years.

8.1.4 Hygiene promotion

By directly reducing transmission of faecal pathogens by hand, improved hygiene offers a potentially important barrier that can prevent contamination of drinking water and food as well as direct ingestion (Figure 8.3).

Health education is based on the premise that knowledge of the health benefit is sufficient to change people's behaviour. Some studies have shown that such cognitive factors are far less effective drivers of change than emotional drives, such as the desire for prestige or concern for one's children (Aunger *et al.* 2010, Scott *et al,* 2008). The concept of hygiene education has been superseded by the broader notion of hygiene promotion, which includes this broader perspective. Hygiene promotion refers to handwashing with soap and other practices that promote cleanliness.

Figure 8.3 – Hygiene barriers to faecal-oral disease transmission



Source: Waddington *et al.* 2009

Handwashing with soap at key events, such as after defecation and after cleaning a baby's bottom, has been shown to reduce morbidity associated with excreta pathogens. Handwashing with soap interrupts the transmission pathway by removing pathogens from fingers, and thus reduces the probability that the pathogens will reach the food or mouth of an individual.

A systematic review of the health effects of handwashing with soap by Curtis & Cairncross (2003) found that washing hands with soap reduced the risk of diarrhoeal disease by 42-47%. The practice reduced morbidity from the most life-threatening diarrhoeal diseases (typhoid and cholera) by a similar proportion – 48%. There is also some evidence that handwashing with soap potential can reduce morbidity from other illnesses, such as Acute Respiratory Infections (ARIs) and ascariasis (Rabie & Curtis 2006; Fung & Cairncross 2009) although the strength of the effect is less certain than for diarrhoea.

Improved personal hygiene, with an adequate quantity of water, could conceivably contribute to reductions in water-washed disease such as ringworm, louse-borne illnesses and potentially scabies, although the size of the protective effect remains to be determined. In specific local settings there may be other aspects of behaviour that deserve attention, for example measures to prevent schistosomiasis or guinea worm disease (Esrey *et al.* 1991).

The evidence-based design of hygiene promotion interventions is a relatively recent phenomenon. There is some scientific basis for choosing which aspect of hygiene behaviour to seek to change. In 1991, Loevinsohn published a review of health education interventions in developing countries (1991). Only three studies passed his elementary criteria of scientific rigour, and only one of those related to hygiene. In the same year, the DFID-funded Oxford workshop on the measurement of changes in hygiene behaviour created for the first time the conditions for objective evaluation of hygiene behaviour change interventions. Evidence-based interventions for hygiene behaviour change thus began only two decades ago.

However, the effectiveness of hygiene behaviour change interventions at scale is usually much less than their efficacy in local trials or examples. Even now much of the literature consists of anecdote, and instead of evidence-based best practice there exist a number of branded models associated particular institutions or individuals. Examples include:

- **Social Marketing** - as used by the Global Public Private Partnership for Handwashing with Soap (www.globalhandwashing.org)
- **Community-led Total Sanitation** (CLTS) - widely used by WaterAid, Plan International and other INGOs (www.communityledtotalsanitation.org)
- **Community Health Clubs** - used with DFID support in the 1990s in three districts of Zimbabwe (www.africaahead.org).

Conclusion: Handwashing and other personal hygiene practices have the potential to substantially reduce within household transmission of diarrhoea and other common infection. Because of confounding and social desirability, personal hygiene is not easy to investigate in randomised controlled trials. Therefore the evidence currently is only suggestive. On the other hand, promoting for example handwashing or safe disposal of child faeces are unlikely to do any harm and can be incorporated in a wide range of public health strategies at low cost.

8.2 Integration of WASH interventions

There are many interconnections between water supply, sanitation and hygiene. Water availability makes hygiene possible; good hygiene helps to prevent re-contamination of treated stored water; use of latrines makes personal hygiene easier; and unhygienic latrines may lead to an increase in flies, mosquitoes and water contamination. Water supply and sanitation both affect trachoma.

It is sometimes noted that reviews of the impact of water supply, sanitation and hygiene do not show a greater impact on health from a combination of interventions than from a single one. In view of the very large margins of error in the findings of these reviews, the difference from a simple additive relationship (in which the benefit from water is added to the benefit from sanitation) is not statistically significant. Moreover, almost all of the studies of sanitation were in fact studies of water supply *and* sanitation. In the circumstances it is not surprising that studies of the impact of water supply and of sanitation produced the same results; they were largely the same studies!

Box 8.1. Filling the evidence gap on the health impacts of sanitation

A systematic review of the effect of sanitation on diarrhoea published by the Cochrane Group (Clasen *et al.* 2010) concluded that there was a 'paucity of evidence' on the effect of sanitation on diarrhoea. Although the studies reviewed suggested a protective effect, no studies randomised the assignment of sanitation.

Partly in response to this finding, randomised impact evaluations are now underway in multiple settings. Trials are underway in Bangladesh and Kenya to determine how water, and sanitation interventions, delivered alone or as part of combined intervention packages, impact child health and well-being.

In Orissa, India, a cluster-randomised trial on the effect of sanitation on diarrhoea is underway to directly address the evidence gap highlighted by the Cochrane Review.

This theme will be discussed in more detail in the next section.

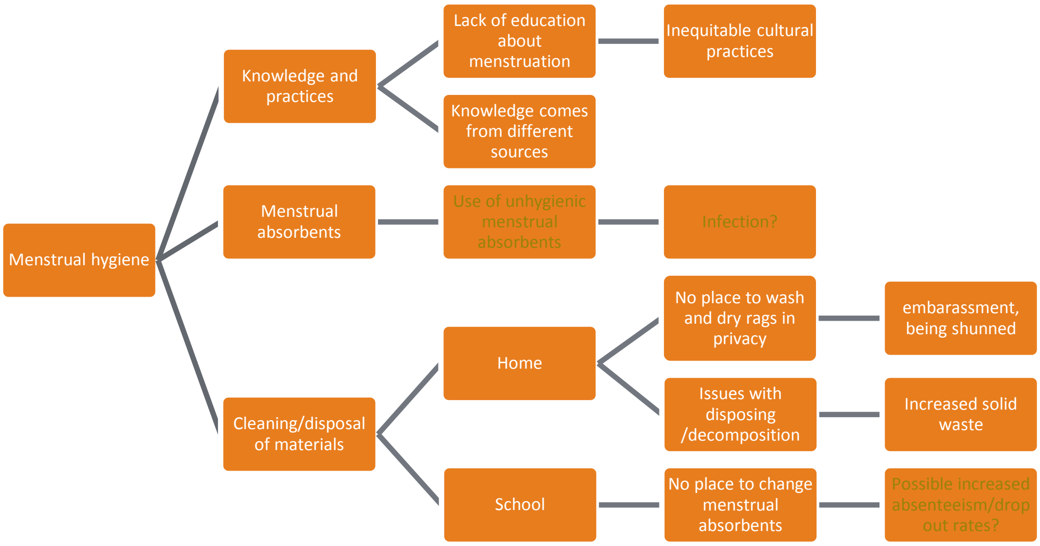
8.3 New 'WASH' interventions

8.3.1 Menstrual Hygiene Management

There is a limited source of quality literature addressing issues of menstrual hygiene in developing countries. This includes but goes beyond issues related to sanitation. Mahon and Fernandes (2010) provide a useful overview of the issue and summarise the needs for adequate menstrual hygiene thus:

Practices and perceptions concerning menstrual hygiene vary drastically between regions and cultures. There are a number of themes commonly addressed in this restricted body of literature: (1) the misconceptions about the physiological aspects of menstruation and where those misconceptions derive from, (2) issues centring on the use of menstrual absorbents (3) problems associated with the sanitary disposal of menstrual absorbents (4) innovative designs for "girl-friendly" toilets and menstrual absorbents and (5) economic impact of menstruation. These themes and their implications are summarised in Figure 8.4. Text in red indicates that little or no conclusive scientific evidence is available on this topic.

Figure 8.4 Themes and implications for menstrual hygiene



Inadequate personal hygiene is known to increase the risk of reproductive tract infections (Bledsoe *et al.* 1994). There is little literature available on the health issues (both long term and short term) associated with the usage of unhygienic materials during menstruation. The grey literature reports an association between non-commercial menstrual absorbents as well as indigenous menstrual hygiene practices and urinary and vaginal infection. However there are very few peer reviewed studies that connect non-commercial menstrual absorbents – or the reuse of menstrual absorbents - with gynaecological health or an increased risk of infection (Bulut *et al.* 1997; Bhatia and Cleland 1995; Drank *et al.* 1995). A Nigerian study suggests that "unsanitary materials such as toilet tissue paper and clothes may harbour infection agents which often thrive under blood culture medium, and may therefore constitute a source of pelvic infection" (Adinma & Adinma 2008).

More research is required on what girls and women consider an acceptable disposal of used sanitary products.

There is no rigorous evidence to show that menstruation is major factor for female drop-out. However, self-reporting by girls suggests that inadequate toilet facilities in schools are a contributory factor for truancy, failing classes, absenteeism, and drop out, particularly in the transition from primary to secondary schools and this may be linked to menarche and the need for appropriate facilities (Abioye-Kutei 2000; Gautum 2010;Jones & Finlay, 2000; Fakeye & Egade 1994; Deo 2007).

One randomised controlled trial was done in Nepal to link school absenteeism with menstruation (Oster & Thornton, 2009). Girls in the intervention group were given a menstrual cup and were followed up to see if the distribution of this menstrual management tool increased school attendance. This study found that it did not have a significant impact on the number of days that girls attended school, however it did reduce the amount of time spent doing laundry (presumably of menstrual rags). The small sample size and atypical method of menstrual management are just two of the flaws identified in this study; however, it is the only one of its kind and does provide a case for larger studies to be done on this issue. Menstruation clearly has the potential to disrupt education, but more studies must be done to confirm this inference and assess possible strategies to minimize absenteeism due to menstruation.

Conclusion: The current evidence base for menstrual hygiene is under-developed and therefore weak

8.3.2 WASH in schools

In many low income settings, water and sanitation facilities at schools are frequently in bad condition or non-existent, with often with poor practice of hygienic behaviour among students. These conditions can be attributed to many factors. Technologies and approaches applied in the schools may be culturally inappropriate, too expensive, and top-down. There may be inadequate and irregular funding for maintenance. Behaviour change messaging remains ineffective: school staff and parents may not understand the urgent need for sustaining improved hygiene behaviours and sanitation facilities. In short there is little universal knowledge of what works (O'Reilly *et al.* 2008).

Although there is significant anecdotal evidence in grey literature that schools lack adequate water and sanitation, governments rarely gather gender disaggregated information on school facilities. There is frequently little or no systematic documentation of project achievements and failures by implementers or dissemination of lessons learned. Cross learning between projects, organizations, or contexts is rare, as is unbiased monitoring and evaluation. However, more recently a number of research projects, including a large RCT in Western Kenya led by Emory University and funded by the Bill and Melinda Gates Foundation, are exploring these issues.

More generally, it should be noted that there is a lack of reliable data on WASH coverage outside of the home, whether this be schools or indeed the work place or even healthcare facilities. The failure to consider the importance of WASH in these other spheres has been highlighted as a major public health risk (Bartram, 2008) and a limitation of the current MDG target (Bartram & Cairncross, 2010).

Conclusion: the evidence base for school sanitation is under-developed and currently weak although large studies are underway that should strengthen our understanding

8.3.3 Food hygiene

It has been estimated that in the USA, food-borne transmission accounts for 37% of episodes of acute gastro-enteritis and 64% of the resulting deaths (Mead *et al.* 1999). The food-borne proportion is highest for bacterial pathogens, which accounts for a greater proportion of episodes in developing countries. A WHO review of the literature assumed that most food-borne disease transmission in developing countries takes place within the home. Indeed food, not water, may be the most important route of transmission of diarrhoea in developing countries (Lanata 2003).

It follows that food hygiene interventions could potentially have a substantial impact on child mortality, especially if targeted towards the foods consumed by young children who contribute to most of the diarrhoea deaths. The WHO review advocated a major programme of interdisciplinary research to develop and test cost-effective interventions to promote food hygiene.

Recent research in Mali showed how a HACCP (Hazard Analysis, Critical Control Point) approach can significantly improve the bacterial safety of weaning food (Toure 2011). Research has been undertaken in Bangladesh, funded by DFID through the SHARE research programme consortium, to confirm whether this approach can be successfully adapted to that context .

Conclusion: Food hygiene in the home is closely linked to other water, sanitation and hygiene issues and may be one of the most neglected research areas in WASH. More studies and intervention trials are needed to improve the currently weak evidence base.

8.4 The interrelation and interdependence of WASH interventions

Ever since the International Water and Sanitation Decade of the 1980s, it has been part of the conventional wisdom that water supply and sanitation should be implemented in an integrated way. Part of the rationale for this policy is to ensure that sanitation is not neglected, and to harness the resources of the water sector. The experience of a number of such combined programs (Cairncross 1992) suggests that in practice one or the other shoots ahead. Usually it is water that runs ahead and sanitation that is left behind.

It is now increasingly accepted that water and sanitation are unhappy bedfellows in project implementation. It takes time to generate demand for sanitation, but water supply construction is best done quickly for the sake of economy. The promotion of hygiene and sanitation thus tends to be rushed and therefore is ineffective, or else genuine promotion is replaced by subsidy (Kar & Chambers 2008) or coercion (Chatterjee 2011), resulting in a loss of sustainability.

Whether or not they are integrated, the three interventions of the WASH sector – water supply, sanitation, and hygiene promotion – depend on one another for the full realisation of their benefits. Thus many sanitation systems cannot function without water. On the other hand when most households have in-house piped water, the wastewater flow often becomes too high for low-cost on-site sanitation systems and the existing drainage channels to cope with, so that septic tanks or sewers are required.

Water is also needed for hygiene practices such as washing hands. In a review of the impact of handwashing with soap on diarrhoea (Curtis & Cairncross 2003) three studies were conducted in locations in which it was clear that little water was available. One was in Lima, Peru where water is bought from vendors by volume; one was in a refugee camp in Malawi and the third was in Burundi where villagers were stated to use only six litres per capita per day. In all three of these settings, the impact of handwashing on diarrhoea was less than the average derived from a pooled analysis, a finding consistent with the likelihood that when water is in short supply, full compliance is hard to achieve.

Other cross linkages are less predictable. One study in Bobo Dioulasso, in Burkina Faso (Curtis *et al.* 1995) found that the yards of properties with house connections were less likely to be contaminated with faeces. Apparently households with the water connection hosed down the yard regularly and this led to the presence of objectionable damp faeces in the yard. These were removed; by contrast, dry faeces were not considered objectionable and were allowed to remain.

The connection between hygiene and sanitation is that both can be promoted in a similar way and by the same human resources. Both can benefit from being allowed to move forward at their own pace. The construction of sanitation facilities themselves involves different skills, and it is a moot point whether promotion and production should be carried out by the same people.

8.5 What characterises 'good WASH'? Safety, sustainability and equity

Evidence about service delivery models

The evidence for health impact from WASH interventions is not strong; evidence regarding the best choice of specific delivery models is weaker still. Moreover, the research questions are so heavily dependent on context that it is almost impossible to compare the findings of studies carried out in different countries or settings. Not the least of the complexities of such comparison is the difficulty of defining appropriate indicators of success. Some would judge a sanitation programme by the scale it achieves, some by its cost effectiveness, others by its sustainability and so on.

A rare example of a study comparing two different delivery models (Whaley & Webster 2011) took advantage of the serendipitous proximity of Community Health Clubs (CHC) and Community Led Total Sanitation (CLTS) programmes in some districts of Zimbabwe. While CLTS was found to be more effective at promoting sanitation, health clubs were more effective at promoting handwashing. While a cost comparison favoured CLTS, the authors argued that both models were so cheap that this was unimportant. In the end, the most useful comments of the authors were in their analysis of factors influencing the effectiveness and sustainability of either approach. In other words, this rare comparative study is most usefully read like one of the descriptive, even anecdotal studies which are more typical of the literature.

Substantial judgement and background knowledge are required for a judicious interpretation of this literature, because each author-practitioner tends to extol the approach adopted by his or her project or agency. In the field of hygiene and sanitation promotion particularly, there is a series of competing branded models for the implementer to follow, each supported by a manual and some anodyne case studies. The apparent rivalry between these models is to some extent an illusion, for two reasons.

First, implementation on the ground often differs substantially from the model conceived in headquarters. For example, the advocates of CLTS put emphasis on the naming and shaming element in motivating people to install a latrine. However fieldwork in Bangladesh, where CLTS was originally developed, found that most latrine owners had invested in sanitation for more positive reasons like those cited by latrine owners around the world – comfort, security, prestige etc. (Allen 2003). It seems likely that fieldworkers altered the message they had been taught to convey, so as to achieve a more effective result.

Second, the models often focus on different aspects of the programme, and can be combined in practice. Thus CLTS focuses on demand creation rather than supply. It has been successfully combined with sanitation marketing approaches to develop the supply side in numerous programmes supported by the Water and Sanitation Program of the World Bank[2].

In this section, we do not aim to judge between alternative models, but to note the consistent features of good WASH programmes.

One key lesson of experience is that all WASH interventions should be seen as processes rather than products. It is not enough to build water supplies or latrines; they must be used and maintained over a reasonable lifetime, and when necessary repaired or replaced. To this end, it will benefit the sector if State or donor investment is not seen as the only source of funding but as seed money to leverage investment by households and communities. Often the State, and particularly local government, can play a more effective role by promotion or appropriate regulation than by direct investment.

For example, building codes could be relaxed to allow low-cost on-site sanitation technologies and urban land tenure legislation revised to require provision of sanitation facilities as a condition for continued ownership of a plot. With regard to water supply, local government can help to create and support local level institutions capable of managing and maintaining a borehole or a well.

In order to plan such interventions, and certainly for hygiene promotion, a period of formative research is required, which may last several months. It should include study of the existing market – providers, consumers, prices etc – and of the factors motivating or constraining the consumer.

Formative research also includes testing of communication materials which it is planned to use. A prime example of the level of detail involved, and of the unpredictability of the results, is provided by the Egyptian oral rehydration programme in 1980s. Focus groups of young mothers were shown the proposed logo of the programme, which showed a mother giving oral rehydration therapy (ORT) to her baby, and asked if they would copy her. The vociferous and angry response surprised even the researchers, until they realised they had forgotten to put a wedding ring on the finger of the woman in the drawing.

Sanitation

Minimising the hardware subsidy and leveraging household investment is often considered the best way to ensure that every latrine built is wanted (Jenkins & Sugden 2006). That will ensure that it is maintained. A consequence of this policy, however, is that the latrine design on offer must be affordable to low income groups. This means that latrines must be designed to a target price and for a market niche, whereas most public health engineers are used to designing to a technical specification. In practice, another implication is that several designs should be offered, catering to different purses and aspirations.

The avoidance of subsidy for the construction of toilets should not be read as an excuse for government to fail to invest in sanitation. There are compelling reasons why they should invest (Bartram & Cairncross 2010), not least, the externality whereby the citizen is protected from excreta by his neighbours' toilets more than by his own. The issue is not whether the public sector should invest, but how. There is plenty of room for public investment in demand creation, and in capacity-building on the supply side, without putting public funds into the toilets themselves, causing distortions in the market.

[2] See: http://www.wsp.org/wsp/node/29 Last accessed September 2011

There is one important policy issue where the evidence is conflicting. Collective or public or community toilets have been a common feature of sanitation programmes in South Asia and are appearing increasingly in East Africa. In the past, it has generally been accepted that while these may function well as a business, they are far from meeting the full need of the community, particularly for children and for the elderly and infirm. They are also usually locked at night. However it has recently been advocated (Joshi *et al.* 2011) that when they are managed by community groups the result is more positive. Recent research by the DFID-funded SHARE RPC in Bhopal, India (Biran *et al.* 2011) has found that only half as many women as men use these toilets, with a rapid decline in usage rates with distance from the home. This pattern was seen irrespective of the arrangements for management of the latrine block.

Given the accounts of violence against women on the way to or from public toilets in Kenya and Uganda (Amnesty International 2010; Massey 2011) it is plausible that such a threat is deterring women in Bhopal from using the facilities. Until further research has been carried out into this issue, a question mark hangs over such collective solutions.

Now that on-site sanitation systems have been in use in some cities for many years, it has become clearer that the sanitation system is not complete unless it allows for pit emptying or at least replacement, and disposal of the pit contents where necessary. There is a case for subsidising this service because of the externalities.

There is some debate among policymakers about whether it is necessary to target sanitation programmes toward the poorest of the poor. In this context it is useful to recall the findings of the sewerage intervention study (Barreto *et al*. 2007) in the city of Salvador, Brazil. Local authorities had expressed concern at the lower rate of connection to this sewerage system by low income households, who were deterred by the connection charge. Nevertheless, the health impact was greatest among the poor, because it was greatest among those neighbourhoods at highest initial risk, and also depended not on the sewer connection of the individual household, but rather on the proportion of households in the neighbourhoods that were connected. Given the externalities of sanitation's health benefits, the argument for targeting the poor is not an open and shut case. Targeting has substantial transaction costs and the example of India shows that it is not always successful. Further research is needed to improve our understanding of these issues.

Water supply

With water supply on the other hand, some targeting may be necessary. The focus should be on communities and households which require the longest journey, particularly of more than 30 minutes, to collect a container of water (Wang & Hunter 2010; Subaiya & Cairncross 2011). If all households are within the distance, they are unlikely to show a health benefit if provided with a public standpost service. In that case especially, priority should be given to providing the maximum possible number of house connections, so as to achieve the health benefits associated with that level of service (Cairncross & Valdmanis 2006).

Of course, any assessment of the health benefit of a water supply presupposes that the system functions reliably. Hunter *et al.* (2009) have shown by quantitative microbial risk assessment that a few days of breakdown can negate all the health benefit, especially to young children, of months of satisfactory functioning. They considered a model in which consumers turned to polluted traditional water sources containing pathogens from which the water supply normally protected them; but the same argument would apply if the system provided a reliable flow, which was unreliable in quality.

With rural water supply, the primary problem determining reliability and sustainability is to establish local institutions for maintenance (Feachem 1980; Cairncross *et al.* 2010b). This is more than setting up a village water committee; it amounts to establishing the embryo of local government.

It might seem that urban conditions are different because different technology is used. But for low income areas it has often been found to be expedient to use small-scale local water systems such as wells and boreholes rather than increasing the burden on an already overstretched and intermittent distribution system. For example pavement dwellers and residents of bustees in Calcutta, adding up to one third of the city's 9 million population, have for the last 30 years used tube wells with handpumps on street corners to obtain water for general hygiene purposes. Such autonomous systems also require local institutions to manage them or at least to report breakdowns.

Even where a large city distribution network is involved, the local community-based organisations can play a useful role in organising the distribution network at local level in low-income neighbourhoods and helping people ensure regular payment for water. Further details of the characteristics of successful programmes are given in the DFID Guidance Manual for Water and Sanitation Projects (DFID 1998).

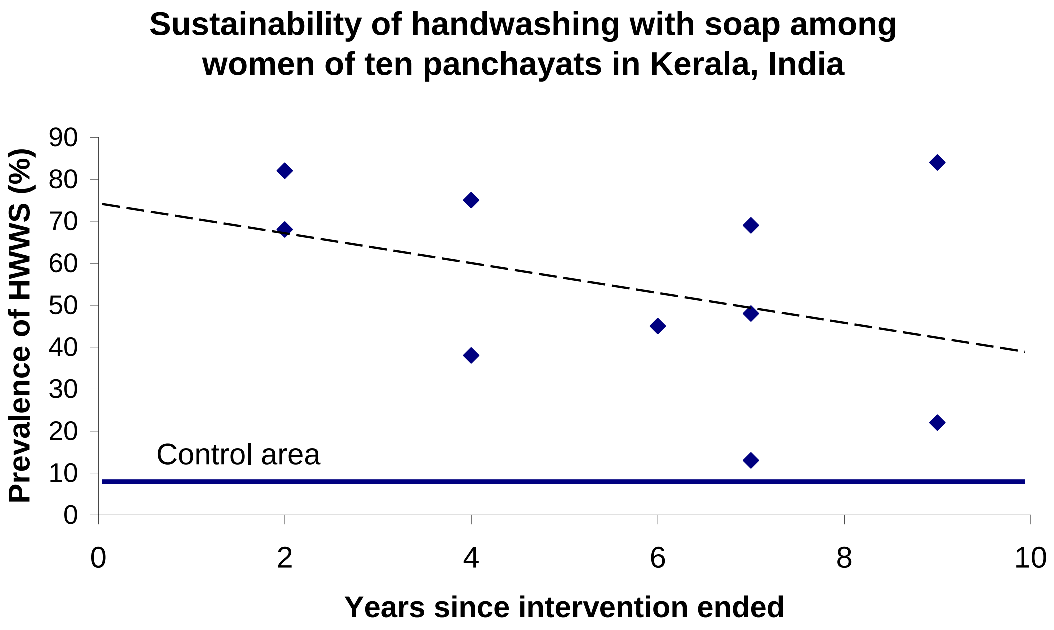
Hygiene promotion

For hygiene promotion, there are so few well documented case studies that it is not possible to draw an evidence-based conclusion about which approach is more effective, but there are some general points which can be made.

Formative research is particularly important in this field, where many people *think* they know what to do. Regarding what hygiene behaviour to promote, the evidence is strongest for handwashing with soap. As mentioned elsewhere, there is also evidence for health impact from hygienic disposal of children's stools; however this is only from observational studies. The experience of successful hygiene promotion programmes and commercial marketing is that one or two contacts with people are not enough; at least six encounters between the average person and the communication programme are required to change behaviour (Curtis *et al.* 2007).

One question on which the evidence base provides conflicting answers is the degree to which behaviour change is sustained. Here we present the positive side of the story. Figure 8.5 below shows the self-reported rates of handwashing by mothers in Kerala (Cairncross *et al.* 2005), India against the time elapsed since the ending of the handwashing promotion campaign in their panchayat. The rate in the control area, and presumably in the ten panchayat before the campaign, was only 7%. The data show no sign of a rapid abandonment of the new hygienic practice. The regression line shown dashed in the figure is consistent with a half-life of 10-15 years, comparable with the rate of inter-generational succession of mothers in the community.

Figure 8.5



Source: Curtis *et al.* 2009

While there are a few other studies whose findings confirm such persistence of hygiene behaviour (Wilson & Chandler 1993), there are others which do not (Luby *et al.* 2009). Until we can predict when hygiene behaviour change will last, we cannot presume that it will. It is necessary to monitor the behaviour and repeat the intervention if its effect is found to fall off with time. Both for research and for such monitoring, there is an urgent need for methods to measure handwashing with soap; three of the five known persistence studies used self-reporting of handwashing, which has long been discredited as an indicator because of people's tendency to be aspirational rather than factual in their responses.

Box 8.2 SHEWA-B programme

Supported by DFID with the technical assistance of Unicef, the SHEWA-B programme aims to improve the hygiene behaviour of 20 million people in rural Bangladesh over five years.

A detailed evaluation by ICDDRB after 18 months of this five-year programme showed that washing both hands with soap or ash after cleaning a child's anus increased from 22% to 36% ($P<0.05$), and the proportion with no access to a latrine decreased from 10% to 6.8% ($P<0.05$) from baseline to 18 months. Other hygiene practices improved in both intervention and control communities. However, handwashing with soap associated with food preparation, handling and consumption remained below 2% of occasions, suggesting how hard it can be to shift a social norm for a rare behaviour. The prevalence of diarrhoea and respiratory illness among children <5 years of age were similar in intervention and control communities throughout the study.

A qualitative evaluation suggested that the programme was probably trying to improve too many practices at the same time, and that a mass media component was likely to be a cost-effective addition to the programme. With sharper, more focused programming and new materials for the 10,000 active hygiene promoters currently being implemented, improved results should be expected.

9. The economics of WASH

9.1 Costs of improving WASH coverage

There is limited systematic data on the costs of providing and sustaining WASH services. Part of the problem is the simple lack of available studies. The second challenge is that costs vary highly based on the setting, the delivery approach and the level of service.

Several studies have ventured to estimate costs at a global or regional level. Table 9.1 below illustrates the costs shown by The Disease Control Priorities Project. The costs are roughly derived from a limited number of studies in disparate settings. They are reported as the authors' assumptions rather than a systematic estimate of the mean cost or a measure of certainty. While the authors attempt to separate out initial versus ongoing costs, most of the original studies do not have adequate data on useful lifetime or annual operations and maintenance costs. There is also no effort to estimate differences across settings. The authors point out that cost estimates from existing studies are both limited and highly variable, with costs differing based on setting and the intensity of the intervention approach. This is particularly true for the behaviour change promotion components. While hygiene and sanitation promotion are relatively inexpensive, their full effectiveness may require investment in the hardware components of water supply and sanitation construction, whether paid for by implementers or beneficiaries.

Hutton colleagues (2007) provide regional estimates of costs based on the Global Water Supply and Sanitation 2000 Report (WHO/UNICEF 2000), combined with author estimates of recurrent costs as a percentage of overall costs (Table 9.2). The regional cost differences are intended to capture some of the variability in cost structures between the varying economic and physical settings. However, there is likely to be substantial variability within regions and countries as well. The authors also make assumptions about the expected life and annual operations and maintenance cost for each intervention. Nonetheless, they acknowledge that there is little consistent empirical data on which to make these estimates. For point of use treatment, the costs are for the intervention technology itself; however it is unclear whether this level of expenditure is sufficient to generate changes in behaviour and use at scale.

While the two reviews provide similar cost estimates for different WASH services, they should be viewed with caution. Neither study provides a transparent description of how costs from different studies are used to generate point estimates; neither assesses the quality of the underlying studies' methods for collection of cost data; and neither includes empirical information on recurrent costs. Lastly, they do not provide breakdowns for costs based on settings or based on conditions (e.g. rural versus urban sanitation or water supply). Nevertheless, they provide an important starting point in identifying knowledge gaps. Similar efforts to estimate the costs of other health interventions at a global level (for instance within Disease Control Priorities Project, Second Edition, (DCP2)) suffer from similar methodological challenge. However the DCP2 report ranked the quality of available cost and cost-effectiveness data for WASH interventions as relatively low, compared to other interventions. In part this is due the wide range of technologies, intervention delivery approaches and environmental heterogeneity.

IRC International Water and Sanitation Centre recently began a multi-year project (WASHCost) to develop consistent methods for estimating the costs of delivering WASH services that may begin to fill these gaps. The project focuses on India, Burkina Faso, Ghana and Mozambique. Three key contributions of this ongoing effort will be to 1) develop consistent and repeatable methods, 2) estimate the ongoing costs to sustain services and interventions and 3) develop an improved understanding of the effect of service level on costs. Published data are not currently available from the project but standardized methods are available. While the study will provide standardized estimates of initial and recurring costs within the study areas in each country, ongoing efforts will be needed to estimate costs in other contexts and countries.

Overall, current costs provide an initial estimate of actual costs associated with WASH interventions. While the estimates help identify knowledge gaps, the single point estimates at the global or regional level obscure substantial uncertainty and variability.

Table 9.1 Costs assumed for cost-effectiveness calculations

Intervention	**Construction cost (US$ per capita)**	**Amortization lifetime (years)**	**Amortized annual cost (US$ per capita)**	**Operation and maintenance cost (US$ per capita)**
Hygiene promotion	1	5	0.2	n.a.
Sanitation	≤60	5	≤12	n.a.
Sanitation promotion	2.5	5	0.5	n.a.
Water supply				
House connections	150	20	7.5	10
Hand pump or stand post	40	20	1	1
Water regulation and advocacy	US$0.02 to US$0.10 per capita per year			

Source: Cairncross and Valdmanis 2006

Table 9.2 Average annual cost of interventions

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

Source: Haller *et al.* 2007

9.2 Estimating the economic burden

Several studies have attempted to estimate the economic burden associated with inadequate water access, sanitation and hygiene, or the economic benefits of improving these services. Potential impacts include: medical treatment costs associated with WASH-related illnesses, productivity losses due to illness and water collection, lost days from schooling, long-term cognitive losses, and others.

One study estimates that the health costs alone amount to some US$340 million for households lacking water supply and sanitation and US$7 billion for national health systems (Hutton & Haller 2004). Another World Bank study found that the value of time saved from water collection alone was sufficient to justify investments in rural water supply in most settings (Churchill *et al.* 1987). And a WHO report suggests that the time lost in collecting water and seeking somewhere to defecate could be valued at US$63 billion annually (Hutton *et al.* 2007).

There are several broad approaches to measuring economic burden of poor water, sanitation and hygiene, each with its own limitations. The most rigorous would involve experimental designs that empirically measure economic and financial improvements in communities or individuals receiving water, sanitation or hygiene. There is little existing evidence of this type due to the methodological challenges of conducting trials of this type.

A second approach is to measure economic outcomes in communities and households with different levels of water, sanitation and hygiene. However, such studies are problematic because household and community economic status confound this relationship, given that poorer households are already likely to have poorer water, sanitation and hygiene.
The third approach is to synthesise existing evidence from diverse sources to estimate health and social outcomes potentially attributable to water, sanitation and hygiene, and then estimate the economic and financial costs associated with each.

The latter approach was used by Hutton & Haller (2004) to estimate the global economic burden of inadequate water, sanitation and hygiene. The analysis is based on the identification of different risk scenarios which entail different qualities of water, sanitation and hygiene access, based on Prüss and colleagues (2002). The estimates include the economic and financial costs relating to medical treatment costs, lost time from productive activities, lost time from productive activities due to water collection, the economic value of premature mortality, and time saving from improved latrines.

This study was an important first step in identifying potential costs associated with inadequate water and sanitation. It also identified key areas where insufficient empirical data are available to make a reliable estimate of economic burden. However, the actual quantitative estimates should be viewed cautiously. The authors acknowledge that data are limited in estimating these benefits and rely on assumptions in order to generate preliminary estimates. For instance the study estimated all cases of diarrhoea among children under five result in approximately two work days lost per reported case due to increased caregiver time. Empirical studies of the household cost of diarrhoea in low-income countries generally find that most cases result in no time lost for work and that those who do lose time, lose less than two days (Bentley *et al.* 1995; Rheingans *et al.* 2007; Chai & Lee 2009). Similarly, among school-aged children it was assumed that each case would result in three days of missed school without empirical basis.

The World Bank's Water and Sanitation Program (WSP) developed six national level studies on the economics of sanitation in Asia for Indonesia, India, Vietnam, Cambodia, Philippines and Democratic Republic (DR) of Laos. The studies included estimates of a range of financial and economic costs. The total costs vary among the countries, primarily based on population size and current level of sanitation. In India, they estimate that the losses due to inadequate sanitation and hygiene cost the equivalent of more than 6 % of Gross Domestic Product.

Few studies experimentally estimated the impact of water, sanitation and hygiene on economic outcomes. However, Pattanayak and colleagues (2010) used a rigorous quasi-experimental design based on propensity score matching to measure the household economic impact of improved sanitation in Maharashtra, India. They found that sanitation resulted in a significant reduction in household expenses related to coping – equivalent to 5% of monthly income. However there was no change in medical expenses.

A recent study by Baird and colleagues (2011) suggests that controlling intestinal helminths can result in long-term economic gains. The study included long-term follow up of economic productivity in a cohort of Kenyan children from schools where deworming was experimentally phased in between 1998 and 2001. Children in intervention schools engaged in the labour force had earnings 21-29% greater than children in non-intervention schools. While deworming is a different intervention to sanitation and hygiene, it is plausible that these improvements could also lead to long-term economic gains in productivity. It should also be noted that helminth prevalence rates vary widely and the study area in western

Kenya has exceptionally high rates. Long-term economic gains may vary due to geography based on underlying helminth prevalence and intensity of infection (Baird *et al.* 2011).

One of the most likely economic costs associated with inadequate water access is the economic value of collection time for adults (in the form of lost work) and children (in the form of lost schooling). However, there are several challenges in estimating the economic burden of these losses (Rosen & Vincent 1999). Individuals within households and communities with lower opportunity costs for their time often engage in these activities, making it difficult to estimate the value of lost time. Similarly, estimating the time gains to women or children from improved water access is challenging empirically because water access and time allocation are likely to be confounded at both the between community and within community level. For example, households may have latent characteristics that lead them to have both better water access and more time allocated to productive activities.

The studies also include time loss associated with non-fatal health outcomes, including time lost for illness among adults, time lost from school for school-aged children and time lost from work for caregivers of small children. These economic burden studies are based on assumptions about the likelihood that illness leads to time loss from productive activities and the amount of time that is likely to be lost. While there is little doubt that these costs exist, there are few if any empirical studies on which to base them.

In addition to the economic benefits of improved sanitation, there is a strong relationship between improved safe water supplies and livelihoods, whether for productive or domestic uses; in wealthier countries, past investment in water infrastructure and the ability to invest more in the present increase water security and, arguably, prosperity (Hunter *et al.* 2010).

9.3 Relative cost-effectiveness and cost-benefit of WASH interventions

Two economic evaluation methods are commonly used to measure the value for money from investments in WASH (and other sectors). Cost-benefit analysis compares the monetary investment in the intervention to the monetary value of the resulting stream of benefits. The result is reported as a benefit:cost ratio based on the monetary value of benefits for each unit of cost investment. The method can capture all benefits that can be translated into monetary units. In the health sector, economic evaluations often use cost-effectiveness analysis, which estimates the health benefit (expressed as Disability-Adjusted Life Years, DALYs) for each net monetary investment. The result is expressed as a cost-effectiveness ratio ($/DALY averted) and is used to compare the *health* return on different investments. Cost-effectiveness analysis does not capture non-health benefits, such as improved education, or economic gains, such as increased earnings.

Both cost-benefit and cost-effectiveness studies must convert epidemiological and impact data on disease incidence into standardised measures of morbidity and mortality. In the case of cost-benefit analysis, this requires estimating impact of mortality and on disease conditions that incur costs (e.g. hospitalisations and outpatient visits). For cost-effectiveness analysis, DALY calculations require estimates of mortality and days (or years) lived with disability. There are several challenges and uncertainties in this process that affect confidence in the resulting estimates.

First, the most significant impact of reduced diarrhoeal illness (both monetary and in terms of DALYs) is due to mortality in low-income settings (Rheingans *et al.* 2009). There are no RCTs that estimate the impact of WASH interventions on diarrhoeal mortality. Such a study would be very costly and likely impractical. Estimating it through other study designs is difficult given confounding of the relationship between WASH and child mortality by economic status. As a result, all of the studies below rely on extrapolations from diarrhoeal incidence to diarrhoeal mortality, by assuming that the case fatality rate remains constant (Prüss *et al.* , 2002; Hutton *et al.* 2007). However, several factors may result in questioning this assumption. WASH interventions may influence particular pathogens (e.g. cholera, shigella) while having a limited impact on others (e.g. rotavirus and noroviruses). If the WASH-affected diarrhoea has a higher or lower case fatality rate, then the estimated mortality would be lower or higher (respectively) than the actual. The WASH-related mortality reduction could also be different from the diarrhoeal incidence reduction if the intervention beneficiaries have higher or lower diarrhoeal mortality than the population as a whole. That is, if a WASH intervention reaches a highly vulnerable population (e.g. poor nutritional status, low access to treatment, immune compromised), then the mortality benefits could be substantially higher. Conversely, if the intervention does not reach these high-risk populations, then the mortality reduction could be substantially less. It is also important to point out that the global cost-effectiveness and cost-benefit studies described below use diarrhoeal mortality estimates that have since been updated.

The second challenge in translating epidemiological and impact assessment evidence to health and monetary benefits for economic evaluations relates to which health outcomes will be included. Most global cost-effectiveness and cost-benefit analyses focus on the diarrhoeal impact of the interventions because the existing evidence is strongest for that outcome. However, this leaves out potential impacts on soil-transmitted helminths, nutrition, adolescent sexual health, maternal mortality and schistosomiasis. This can result in an underestimate of the value for money of WASH interventions. However, it can also result in inconsistent and biased estimates making it difficult to compare the cost-effectiveness of different WASH interventions and to compare WASH interventions to other health and development interventions.

9.3.1 Cost-benefit analyses

Several cost-benefit studies have been carried out of WASH interventions at the global level. One of the most cited is a series conducted for WHO and the Human Development Report (Hutton & Haller 2004; Hutton *et al.* 2007). The related studies and publications estimate the costs and economic benefits of different WASH interventions based on WHO regions. The study attempts to take into consideration the existing service quality, coverage levels and underlying diarrhoeal mortality, in order to account for expected heterogeneity in health impacts. The benefit estimate approach is based on that presented by Prüss and colleagues (2002). The study considers the benefit:cost ratio for 5 different investment scenarios in each region: 1) meeting the water MDG, 2) meeting the water supply and sanitation MDG, 3) universal access to water supply and sanitation, 4) universal access plus disinfection and 5) regulated piped water and sewerage connections. In all regions and for all scenarios, the benefit to cost ratio was greater than 1, and ranged from 2.1 for piped water and sewerage in Africa to 45.5 for meeting the water and sanitation MDGs in the Americas. The benefit cost ratio for meeting the MDGs ranged from 5.5 in Africa to 26.3 in the Eastern Mediterranean. These results suggest that the estimated monetary value of all of the scenarios provides excellent value for money in all contexts, with the economic value of returns greatly exceeding costs.

While the study suggests that WASH is an excellent development investment, caution must be used in interpreting the quantitative estimates. First, as pointed out in the section above on economic benefits, there is a substantial uncertainty regarding some elements of the estimated economic returns. Eighty-two percent of the total monetary value of benefits is based on the improved convenience from WASH improvements. However, there is limited empirical evidence that quantifies the time-savings from WASH interventions or the economic value of the time savings. That is, it is unclear whether improvements in convenience would result in improved incomes. The second largest monetary benefit is that associated with the value of deaths avoided. Given the uncertainty in these key benefit measures, it is unclear whether the quantitative estimates are sufficiently accurate to be able to distinguish between the different scenarios. These estimates would be greatly improved with improved empirical data regarding the assumptions of economic benefits or from rigorous studies that directly measure economic outcomes.

9.3.2 Cost-effectiveness analyses

Compared to cost-benefit studies, cost-effectiveness analyses avoid the problem of estimating the monetary benefit of interventions by focusing solely on their health impacts. Given the high potential economic benefits estimated in the cost-benefit studies, this may result in an underestimate or a biased estimate of the impact of different interventions. For example, if water supply interventions provide substantial time savings, but moderate health benefits, then a cost-effectiveness analysis may show it to be less favourable than hygiene, while a cost-benefit analysis may show it to be more favourable.

While there are a number of site-specific studies of cost-effectiveness of particular WASH interventions, we focus here on two prominent global level analyses. Site-specific studies of cost-effectiveness can be very informative to local and national sector actors, however heterogeneity in contexts and methods reduces that value in a sector-wide review.

The World Bank/WHO Disease Control Priorities Project judged most interventions in WASH in developing countries to be highly cost-effective health interventions in comparison with other public health interventions (Cairncross & Valdmanis, 2006). Table 9.3 shows the results of The Disease Control Priorities Project cost effectiveness analysis. The cost estimates are described above and the benefit estimates focus on the expected impact on diarrhoeal mortality. The most cost effective of all major disease control interventions are hygiene promotion and sanitation promotion at US$5 and US$11 per DALY respectively. Although these figures do not consider the construction costs of water and sanitation facilities (which would lower cost-effectiveness if included) or the indirect costs of malnutrition (which would increase cost-effectiveness if included).

The estimated cost-effectiveness ratios for sanitation construction and handpumps or standposts are less favourable ($270 and $94/DALY). However, this difference should be interpreted with caution. Since non-diarrheal outcomes such as soil-transmitted helminths, trachoma and nutrition are not included, it is unclear whether the relative cost-effectiveness would remain the same. In general, interventions with a cost-effectiveness ratio of less than the national Gross Domestic Product are considered ‘highly cost-effective’. Those with a cost-effectiveness ratio less than three times the GDP are considered ‘cost-effective’. For most low-income settings, this would make WASH interventions highly cost-effective. Some of these figures compare very favourably with the figure for Oral Rehydration Therapy of US$23/ DALY.

Table 9.3 Cost-effectiveness of hygiene, sanitation and water supply (US$/DALY)

Intervention	Cost-effectiveness
Hygiene Promotion	3.35
Basic Sanitation	
Construction and promotion	≤270
Promotion only	11.15
Water Supply	
Hand pump or stand post	94
House connection	223
Water sector regulation and advocacy	47

Source: Cairncross & Valdmanis 2006

Haller and colleagues (2007) use a similar approach to estimate the cost-effectiveness of five WASH interventions for each WHO region and mortality strata. The study accounts for different levels of current coverage and mortality as described for the cost-benefit study above. The interventions are: (1) meet the MDGs on water supply and sanitation; (2) disinfection at point of use; (3) 98% coverage of water supply and sanitation; (4) 98% WSS coverage and disinfection; and, (5) piped water and sewerage connection, Point of use disinfection was estimated to be the most cost-effective with a CER ranging from $20/DALY in AFRO-D to $684 in AMRO-B, well below the regional GDP in each. Most other interventions were determined to be cost-effective as well, but somewhat less favourable. This should not be interpreted as meaning that only point of use should be done, but rather that it may be the most efficient intervention to start with.

Comparisons of the cost-effectiveness of WASH versus other interventions at a global or even regional level should be viewed with caution. The cost-effectiveness of investment in any area depends on the underlying burden of disease and what interventions are already in place. Comparisons of WASH to other areas such as HIV/AIDS or malaria only have meaning in particular contexts where results are adjusted based on the underlying burden of each disease. Even then, they should be viewed with caution.

Moreover, the dearth of high quality studies to provide the evidence of direct impacts on diarrhoeal diseases for some interventions, make the cost-effectiveness figures reached questionable.

The existing evidence suggests that WASH interventions, like many other poverty alleviation and health interventions, are highly cost effective. However, the existing evidence is generally inadequate to determine whether WASH investments are significantly more or less cost-effective than other interventions, given uncertainty and the variability in benefits across settings.

Given these uncertainties, caution should be used in interpreting the relative cost-effectiveness of the different WASH interventions. Limited empirical data is available on the relative sustainable, long-term costs, and non-diarrhoea benefits. In addition, it is quite likely that relative importance will differ between settings based on the existing dominant transmission pathways.

9.4 Discussion

There is substantial evidence that WASH interventions can lead to significant health, economic and development benefits. However, the exact magnitude of these benefits remains highly uncertain. In addition, the sector currently lacks the needed information to maximise the return and value for investments.

Current estimates of economic and health benefits of WASH interventions do not utilise existing best practices for estimating uncertainty regarding quantitative benefit estimates. Probabilistic simulation methods have been recommended and used to estimate the certainty bounds for health and economic benefits of other diarrhoeal prevention interventions (Rheingans *et al.* 2009), and these should be used for estimating the impacts of WASH interventions in an objective manner.

There is a need for a transparent and externally validated model to convert epidemiological and RCT results of WASH efficacy into estimates of DALY and economic improvements. Such an effort would capture the diarrhoeal, nutritional and intestinal parasite impacts of interventions. There are existing models, such as LiST, which could be the foundation for such an effort (Fischer-Walker *et al.* 2011). In the absence of such a consensus, current estimates are often seen as being motivated by advocacy rather than objective, evidence-based approaches. External scientific scrutiny and review can increase confidence in prioritised investments.

In addition to improving the accuracy of estimates there are several areas in which improved economic evaluation information could *directly* result in improved efficiency of investments and value for money. In particular there is very little evidence to guide decision makers about how to invest efficiently *within* the sector at a given scale (local, national or regional). Current estimates are regional at best, and the actual value is likely to differ substantially depending on where the investments occur. Decision support models that translate existing evidence on effectiveness and cost-effectiveness could provide decision makers with information where to invest, what interventions are most cost-effective in particular regions, and what makes sense in rural and urban settings. In addition, value for money is likely to vary greatly based on who benefits, based on large within country differences in underlying disease burden based on geography or socio-economic status. Quantitative estimates of cost-effectiveness associated with reaching different regions and risk groups could allow for redirecting investments and maximising value for money.

Conclusion:

Overall there is good evidence that WASH investments can have significant health, economic and development benefits and that these investments may have a level that is comparable or favourable to other interventions in term of cost-effectiveness. However current estimates of cost-effectiveness are limited by incomplete data and accompanying modelling regarding the impact of WASH investments on non-diarrhoeal outcomes throughout the life-course, as well as the lack of data of costs and variability across settings. Improved estimates of costs, evidence of additional impacts, and synthesised analyses could improve the inefficiency of investment within the sector and better prioritise decisions between sectors.

10. Strengthening the evidence base

10.1 Gaps in knowledge; both theoretical and operational

As with most areas of health and development, there are a number of gaps in our understanding of the magnitude and mechanisms of the impact of WASH interventions on health and development. This section serves to highlight some of these gaps, most of which are addressed elsewhere within the report.

Broadly speaking, these gaps can be grouped into the following categories:

- ***Impact of sanitation on diarrhoea.*** There is some evidence, albeit problematic, for the efficacy of water quality, water quantity, and hygiene diarrhoeal diseases based on experimental intervention studies. However, as has been highlighted in recent systematic reviews (Waddington *et al.* 2009; Clasen *et al,* 2010), there is little rigorous evidence for the efficacy of sanitation in general and for low-cost onsite sanitation in particular, in part due to the challenges of measuring these effects in randomised trials.

- ***Environmental transmission.*** From the earliest investigations of water-borne outbreaks, such as those conducted by John Snow (1855), it has been clear that understanding the specific pathway for environmental contamination and human exposure to that contamination is essential in determining what intervention is appropriate and likely to lead to the greatest impact. Although certain WASH-related transmission pathways are likely to be found in many different contexts in low-income settings, the relative strength of the pathways and their particular characteristics are likely to change based on local conditions. WASH investment decisions are often driven by generalised estimates of impacts (averaged across multiple settings) rather than based on careful assessment of pathways and corresponding interventions. This can lead to overlooking important pathways (such as contamination of complementary foods for infants due to inadequate hygiene) and missed opportunities for maximising health outcomes.

- ***Modes of action of enteric exposures.*** Acute diarrhoea is one of the most obvious signs of inadequate access to improved WASH. However, there is a growing understanding that WASH-related enteric exposures can lead to a much wider range of outcomes throughout the life-course. This includes potential nutritional impacts associated with chronic exposures, interactions with other infectious diseases (e.g. respiratory infections), cancer, and potentially other chronic diseases such as diabetes (Fekadu *et al.* 2010). Improved understanding of immunosenesence and epi-genetics of specific enteric exposures could substantially improve our understanding of the impact of WASH exposures and interventions on other health outcomes.

- ***Non-diarrhoeal outcomes – Beyond the F-Diagram.*** WASH impact studies and meta-analyses tend to focus on the impact of interventions on acute diarrhoea. This is understandable given the importance of this outcome on child mortality and the apparent ease in measuring short-term changes in incidence. However, WASH interventions are likely to have an impact on a much broader range of outcomes. Investments in understanding the impact of sanitation and hygiene on the effectiveness of nutritional interventions (as mediated by tropical enteropathy for example) is part of this. However the effects potentially exceed beyond this. Evidence from recent rotavirus (and other) vaccine trials suggests that environmental enteric exposures may reduce the immune response to and effectiveness of vaccines (especially live oral ones). Similarly, based on transmission dynamics, sanitation and hygiene improvements are recognised as key factors in the control of neglected tropical diseases (NTDs) such as schistosomiasis, trachoma, soil-transmitted helminthes, and cysticercosis. Huge investments in the control of these diseases through preventive chemotherapy have largely ignored the environment control dimensions. Another example is the impact of WASH on maternal mortality through improved hygienic conditions during delivery and the potential effect on reduced birth complications through improved nutritional status earlier in life. Impact of WASH on chemical contaminants such as arsenic or fluoride, and interventions effectiveness also require more attention. Poor WASH conditions may also exacerbate the effect of other conditions including HIV/AIDS, respiratory infections and physical disabilities. For all of these areas there is strong evidence of the biological plausibility of the impact of WASH, but limited systematic evidence of intervention impact. Measuring these impacts in intervention assessments would allow for a more unbiased assessment of the value for money of WASH interventions compared to other interventions and selecting what WASH strategy makes sense in a given context.

- ***Health consequences of WASH as a human need.*** The health impact of WASH is often associated with the impact of interventions on enteric exposures. However, water, sanitation and hygiene relate to the basic human need for drinking, bathing and defecating, and the absence of appropriate WASH conditions can lead to a range of health-related consequences. Poor access conditions can magnify the impact of physical disabilities. Lack of water for bathing and cleaning can affect trachoma, wound management associated with lymphatic filariasis, and perhaps most importantly menstrual hygiene management for women and adolescent girls. Poor access to sanitation can also result in the risk of sexual assault for women (Amnesty International 2011), and poor access to water can result in safety risks and large calorific expenditures for women and children. While there is evidence that these effects exist, there is limited evidence for quantifying the magnitude of the burden or assessing the effectiveness of potential interventions.

- ***Non-health outcomes***. In addition to their health impacts, WASH interventions may be central to a range of non-health development outcomes. One of the most likely, or at least most hypothesised, is the impact of household and school WASH on educational outcomes, especially for girls. This effect may be through enteric and respiratory infections or it may be through the need for appropriate water and sanitation for menstrual hygiene management for girls. There is a growing body of rigorous research on these impacts. However, most studies remain short-term and do not capture the long-term impacts on human development and gender equity. In addition, there is limited systematic information on the magnitude of the problem or what strategies are most effective and cost-effective in addressing it.

- ***Vulnerable populations.*** The value for money for WASH interventions is likely to differ substantially depending on whether it reaches the most vulnerable populations. Undernourished children, children with poor access to treatment, urban slum dwellers with high levels of environmental exposures, adolescent girls, people living with HIV/AIDS and the physically disabled are all likely to be particular susceptible to poor WASH conditions. There is limited quantitative data on the burden within these particular populations and on the most effective and cost-effective strategies for addressing their needs in particular contexts.

- ***Behaviour change, especially at scale.*** Behaviour change is central to many hygiene, sanitation and water quality interventions. However, effective methods for creating and sustaining behaviour change at scale remain limited. Improved understanding of drivers of behaviour change and habit provide key insights into what may be effective, but there is still a great need to identify the most effective ways of translating this into sustained behaviour change at scale.

- ***Costs and cost-effectiveness.*** The costs and cost-effectiveness of different WASH interventions are likely to change substantially, depending on the social and physical context. Improved and better information on the costs and cost-effectiveness provide a starting point for selecting the most appropriate and efficient interventions for a given context. Building the currently limited knowledge and information base is key to making better investment decisions and securing greater value for (public) money.

10.2 Improving methods for measurement of exposure and outcome

Improved evidence-based investment in the WASH sector not only requires additional evidence, but also improved research methods to better capture outcomes and discern the effects of interventions. Improved methods can be grouped into the following categories:

1. Improved measures of outcomes
2. Improved impact study designs
3. Improved methods for understanding heterogeneity in impacts
   (or ‘what works where and why’)

10.2.1 Improved measures

Self-reported data for diarrhoeal and other faecal-oral diseases are a source of potentially significant bias. A number of alternative measures have been suggested. Some of the more promising emerging options are summarised below.

- ***Weight-for-age z-score (WAZ) as a proxy marker for diarrhoea***
  Schmidt and colleagues (2010) have proposed a weight-for-age measure that may be useful in detecting recent diarrhoeal disease in children, based on the fact that recent episodes of diarrhoeal disease may result in short-term weight loss. In a retrospective study of data from two large vitamin A trials from Ghana and Brazil that measured diarrhoeal disease and included biometric data from children, a strong linear association was observed between diarrhoeal occurrence over 14- and 28-day time periods and reduced WAZ. The biometric data used to calculate a WAZ score for children are easily obtainable in a field setting. This measure does, however, have low specificity for detection of diarrhoea: reduced WAZ may be associated with a number of other conditions, including respiratory infections or fever. Whilst lower specificity of the WAZ measure presents challenges with respect to study design, it may be a promising alternative to self-reported diarrhoeal disease.

- ***Salivary antibody measures as pathogen-specific markers for infection***
  Novel analytical methods (Griffin *et al.* 2011) make possible the detection of recent infection and disease events via immunological markers (e.g. pathogen-specific IgG) present in saliva samples. Previously, exposure to faecal-oral pathogens could be tracked by analysing blood samples (Khan *et al.* 2004) and generally for only one

disease agent at the time. These new measures allow testing for the presence and magnitude of antibodies to a wide range of target microbes, including the principal agents responsible for diarrhoeal disease, in non-invasive saliva samples The data from initial and limited field trials show a marked increase of pathogen-specific antibodies associated with recent disease events (seroconversion) in cases compared with controls, and that this apparent increase is detectable for several weeks following infection or illness. These assays may also provide information about previous infections and chronic disease, since past exposures result in low-level detectable antibodies in those exposed. More work is needed, however, to "calibrate" these methods among populations with high disease burdens, so that saliva antibody testing is sufficiently specific and sensitive to be useful in tracking disease events in populations with high exposure to, and subclinical shedding of, faecal-oral pathogens.

- ***Polymerase Chain Reaction (PCR) methods and epi-genetics***
  PCR methods are now fairly commonly used to identify specific pathogens in stool samples. However, high throughput PCR that can test for large numbers of sequences are now being used to understand a much broader range of intestinal conditions. These methods have been used to species diversity and family abundance of gut flora as a way of better understanding exposure, susceptibility and adverse effects (Mai *et al.* 2011; Mai & Draganov 2009). These methods are not intended to provide a substitute for the accurate measurement of discrete health outcomes such as diarrhoea. Instead, they may provide early measures of long-term effects such as those on nutrition, help explain heterogeneity of effects within a population (especially among vulnerable individuals), and shed light on how and when different interventions impact health.

10.2.2 Improved methods for health impact assessment in WASH interventions

Any method used to assess public health interventions must provide effect estimates that are sufficiently valid to inform future policy. This may sound trivial, but surprisingly is one of the most commonly neglected principles specifically in the evaluation of WASH interventions. Often it is claimed that one should judge the merit of different WASH interventions based on the "best available evidence". If no reasonably unbiased evidence is available, the merits of different interventions are better judged based on biological plausibility, non-health benefits or intermediary outcomes, risks and aspects of scalability and logistics (Ross *et al.* 2006; Schmidt & Cairncross 2009).

Only experimental studies with a randomised assignment of intervention and control can deal fully with the issue of confounding by unknown factors but these are expensive and are generally of limited external validity for WASH interventions. Experimental studies – or RCTs – are important and necessary for proof of concept. However, there will never be a sufficient number of RCTs conducted – nor would it be cost-effective to do this – to address the multiple and diverse contexts within which WASH programmes and policy are implemented. As such, and as discussed in previous sections, other study designs should be exploited in order to expand our understanding of what works where and why.

Case-control and cohort studies

Case control and cohort studies are the classic study designs in observational studies. To the extent that selection of controls is not random, and potentially biased, case-control studies are at risk of selection bias. Case-control studies and cohort studies have in common that they are susceptible to confounding, i.e. failure to account for factors that are related to exposure (e.g. sanitation) and outcome (e.g. diarrhea) producing a spurious association.

A key problem with using case-control or cohort designs to evaluate WASH interventions is that adoption of and compliance with water, sanitation and hygiene improvements is highly associated with socio-economic status, education and “modern lifestyle” (Schmidt *et al.* 2009a). All of these potential confounding factors are difficult to measure accurately and therefore to adjust to in the analysis. The potential for confounding in case control and cohort studies studying factors related to WASH is very large and as such this evidence should be treated with caution. Previous cohort and case-control studies evaluating WASH interventions have show very large effect sizes for health outcomes, whether on diarrhea, child mortality or height for age z-score (Azurin and Alvero 1974; Hoque *et al.* 1996; Nanan *et al.* 2003; Young and Briscoe 1988).

Randomised controlled trials

While ecological analyses are often, and for good reason, regarded as the weakest form of evidence used in public health, randomised controlled trials (RCT) are generally regarded as “the gold standard”. This is correct but only under certain conditions. RCTs control for known and unknown confounding and work well if the treatment and the outcome assessment can be blinded both from the study participant and the observer. For WASH studies, it is simply not possible to blind many of the interventions resulting in inevitable bias.

RCTs still can provide largely unbiased estimates if the outcome is an largely objective measure such as weight gain, worm infection or death, though these have rarely been used in WASH trials. In contrast, and as is the case with many WASH RCTs, using a more subjective outcome measure, such as self-reported diarrhoea, may not provide an unbiased estimate. Study participants in the intervention arm have a strong incentive to under-report disease for fear of being seen as non-compliant. Those in the control arm have incentives to over-report disease because they may want to gain access to the intervention. Also, individuals of lower socio-economic status and education who have a particularly high risk of disease tend to be lost to follow up more often. Drop out can be different between the intervention and control groups, thus introducing additional bias. Another source of bias could come from over-enthusiastic field workers who out of commitment, or for the sake of job security, want to demonstrate the effectiveness of an intervention (observer bias).

For these reasons, it can be argued that the term “gold standard” for randomised unblinded studies on environmental health interventions using subjective outcomes is misleading. Instead, RCT data should be interpreted judiciously and alongside data from other epidemiological study designs and qualitative research methods.

10.2.3. Improved methods for understanding heterogeneous impacts

Impact assessment methods are typically focused on rigorously assessing the relationship between an intervention or exposure and a specific, controlling for factors that might differ across a study area such as implementation differences, behaviour uptake, population characteristics and environment. In most impact study designs this heterogeneity increases variance and methods are used to control for these differences in order to estimate the main effect of the intervention or exposure. However, in many cases this heterogeneity hides important information on who is likely to benefit, what aspects of the intervention are essential, and why the intervention may fail or succeed in certain locations. This information may also be important in understanding how well the results from a particular context can be generalised to other settings.

Several analytical techniques have been successfully applied to other health and development problems and interventions:

Instrumental Variables (IV)
Experimental designs such as RCTs rely on the assumption that assignment to an intervention group is a good indicator of exposure to an intervention or elimination of a particular exposure. For example, being assigned to a sanitation study arm is used as a proxy for exposure to improved sanitation, however it may not actually correspond to improved sanitation due to poor delivery or inadequate changes in behaviours. In the context of randomised trials, instrumental variables methods allow researchers to examine the effect of the actual exposure (e.g. observed improved sanitation) on the outcome of interest, while using the experimental randomisation to control for measured and unmeasured confounders. While the method lacks some of the rigour of typical analysis of RCTs, it can provide an important complement to understand the effectiveness of the actual WASH improvement rather than the effectiveness of the particular intervention as implemented – especially with uneven compliance.

Dynamic modelling and Bayesian analysis
Traditional statistical methods focus on drawing inferences from the association between exposure and outcome while controlling biases. In complex social and environmental contexts these relationships are mediated through the environment and mediated by underlying conditions. One way to address this is to explicitly analytically model the effect of underlying conditions and the mediating role of the physical or social environment. This approach has been applied to malaria (Tatem and Smith 2010), schistosomiasis (Liang *et al.* 2007), cholera (Mukandavire *et al.* 2011), and soil transmitted helminths (Pullan *et al.* 2011). Direct observations on exposures and intermediate outcomes such as environmental contamination can be used to revise and refine the underlying model, often with the application Bayesian statistic or other iterative methodologies such as machine learning. Unlike RCTs, these analytical approaches are not primarily designed to determine whether an intervention affected a particular outcome. Rather they are designed to better understand how systems and interventions work and how that may change in different contexts. It complements RCTs by informing intervention improvements and understanding whether and how results may be extrapolated to other settings, two particular weaknesses of traditional methods.

Impact modelling
Health impact models provide an additional tool for estimating the impact of alternative interventions for different settings and sub-populations. More advanced tools that take full advantages of the methodological developments with risk analysis and other fields could help understand the contribution of different WASH interventions to a range of acute and chronic conditions associated with infectious and chemical exposures.

10.3. Enduring questions

The strength of the existing evidence strongly suggests that investment in WASH can yield important health and human development impacts, as well as providing good value for money compared to other interventions. However, the list of knowledge gaps at the beginning of this chapter also suggests that improved knowledge could improve the effectiveness of interventions and investments in the sector. Each of the knowledge gaps could easily generate a list of potential applied or basic research questions. Here we highlight a select few which may lead to significant incremental improvements in effectiveness and value for money.

- **What are the dominant transmission pathways in particular contexts and how does this influence the selection of intervention strategies?** This is the key question that John Snow addressed in responding to the cholera outbreaks of the 1850s (Snow 1855). The same is true for non-epidemic settings as well. Over 150 years later, the analytical tools for assessing exposure have grown enormously, however they are seldom used for choosing or refining intervention strategies. Other disease control efforts such as malaria and schistosomias control have benefited greatly from applying dynamic and spatial modelling to improve the effectiveness of interventions, especially when going to scale. A similar effort for WASH would be extremely helpful in translating the findings of RCTs and other impact assessments to making national and regional investment decisions.

- **How can genetic and epi-genetic patterns be used to develop improved interventions?** John Snow's other transformative contribution was to apply germ theory to understanding the selection of effective interventions. Today, molecular genetics and epi-genetics (how genes respond to the environment) provide powerful tools for understanding how pathogens interact with their environment and the complex ways in which pathogens affect human health – not just through infection but through immune function and nutritional response. Applying these basic science innovations to WASH exposures could identify new intervention strategies, help target vulnerable areas, or select the most cost-effective strategy.

- **What are effective methods for designing effective and locally relevant at-scale behaviour change interventions that work in particular contexts?** Handwashing is one of the most effective disease control strategies in developed and developing countries and programmes at scale are often ineffective in generating sustained behaviour change. Filling this gap requires continued development of our understanding of behaviour change processes, but also our understanding of how to effectively translate such knowledge into programmes at scale. It also requires improved understanding of how factors such as markets can be used to drive and support behaviour change. This applies equally to sanitation where sustaining use and maintenance of facilities by all is critical to realising the potential benefts.

- **What are the health and development impacts of WASH interventions throughout the life-course, and how can they be maximised?** Although this is relevant to all populations, this is particularly relevant for adolescent girls and young women who are affected by health and non-health consequences of poor WASH conditions. This requires improved understanding of the environmental, biological and social processes that generate these impacts, how they build and cascade over time, and what interventions are effective in reducing these impacts.

- **What works where and why?** While there is sufficient evidence to suggest that investments in WASH can provide good value for money, the realization of this potential depends on selecting the right strategy and deciding who is targeted. This requires a concerted effort at translational research to assist sector actors in identify and implementing the most effective and cost-effective strategies. This is particularly true in challenging settings such as urban slums or schools where the actual return on investment will depend on the specific approach and implementation.

References

Acharya A, Paunio M (2008) Environmental health and child survival: epidemiology, economics, experiences. Washington DC: World Bank.

Adams J, Bartram J, Chartier Y, Sims J, eds. (2009) Water, sanitation and hygiene standards for schools in low-cost settings. Geneva: WHO.

Adinma ED, Adinma JI (2008) Perceptions and practices on menstruation amongst Nigerian secondary school girls. Afr J Reprod Health12(1): 74-83.

Adugna A, Dery M, Gomme J, Kalimuthu A, Kashililah H, Kebede M, Owusu E, Radha N, Maganga S, Saywell D (2001) Looking back: participatory impact assessment of older projects. London: WaterAid.

Agha S (2000)The determinants of infant mortality in Pakistan. Soc Sci Med 51(2): 199-208.

Agunwamba JC (2001) Analysis of socioeconomic and environmental impacts of waste stabilization pond and unrestricted wastewater irrigation: interface with maintenance. Environ Manage 27(3): 463-76.

Ahmed SM, Adams AM, Chowdhury M, Bhuiya A (2000) Gender, socioeconomic development and health-seeking behaviour in Bangladesh. Soc Sci Med 51: 361-71.

Aiello, A E, Coulborn, R M, Perez, V & Larson, E L (2008). Effect of hand hygiene on infectious disease risk in the community setting: a meta-analysis. American Journal of Public Health, 98, 1372-81.

Aiga H, Umenai T (2002) Impact of improvement of water supply on household economy in a squatter area of Manila. Soc Sci Med 55(4): 627-41.

Allen S (2003) The WaterAid Bangladesh/VERC 100% sanitation approach: cost, motivation, and subsidy. London: London School of Hygiene and Tropical Medicine.

Amnesty International (2010) Insecurity and indignity: women’s experiences in the slums of Nairobi, Kenya. London: Amnesty International.

Argos, M., T. Kalra, et al. (2010). "Arsenic exposure from drinking water, and all-cause and chronic-disease mortalities in Bangladesh (HEALS): a prospective cohort study." The Lancet **376**(9737): 252-258.

Armienta M A, Segovia N (2008) Arsenic and fluoride in the groundwater of Mexico. Environ Geochem Health 30(4): 345-353.

Aunger R, Schmidt WP, Ranpura A, Coombes Y, Maina PM, Matiko CN, Curtis,V (2010) Three kinds of psychological determinants for hand-washing behaviour in Kenya. Soc Sci Med 70: 383–91.

Azurin JC, Alvero M (1974) Field evaluation of environmental sanitation measures against cholera. Bull World Health Organ 51: 19-26.

Baba A, Tayfur G (2011) Groundwater contamination and its effect on health in Turkey. Environ Monit Assess

Bain RES, et al. (2012) Accounting for water quality in monitoring access to safe drinking-water as part of the millennium development goals: lessons from five countries. Bull World Health Organ [serial on the Internet]. 2012 Mar [cited 2012 Sep 20] ; 90(3): 228-235.

Baird S, et al. (2011) Worms at work: long-run impacts of child health gains. San Francisco: UC Berkeley.

Bapat M, Agarwal I (2003) Our needs, our priorities: women and men from the slums in Mumbai and Pune talk about their needs for water and sanitation. Environment and Urbanization 15(2): 71-86.

Barreto ML, Genser B, Strina A, Teixeira MG, Assis AMO, Rego RF, Teles CA,. Prado MS, Matos SMA, dos Santos LA, Cairncross S (2007) Effect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil: assessment by two cohort studies. Lancet 370:1622-1628. DOI:10.1016/S0140-6736(07)61638-9.

Barreto ML, et al. (2010) Impact of a citywide sanitation program in Northeast Brazil on intestinal parasites infection in young children. Environ Health Perspect 118(11): 1637-42.

Bartram J (2008) Flowing away: water and health opportunities. Bull World Health Organ 86(1):2.

Bartram J, Cairncross S (2010) Hygiene, sanitation, and water: forgotten foundations of Health. PLoS Med 7(11): e1000367. doi:10.1371/journal.pmed.1000367.

Bartram J, et al. (2012) Getting wet, clean, and healthy: why households matter, The Lancet, Volume 380, Issue 9837: 85-86.

Barzilay EJ, et al. (2011) Diarrhea prevention in people living with HIV: an evaluation of a point-of-use water quality intervention in Lagos, Nigeria. AIDS Care 23(3): 330-9.

Bateman OM (1994) Health and hygiene behaviour: hygiene behaviour in an epidemiologic perspective. In: Cairncross S, Kochar V, eds. Studying hygiene behaviour: methods, issues, and experiences. New Delhi: Sage Publications: 26-35.

Benn CS, Martins C, Rodrigues A, Jensen H, Lisse IM, Aaby P (2005) Randomised study of effect of different doses of vitamin A on childhood morbidity and mortality. BMJ 331: 1428-32.

Bentley M E, Elder J, et al. (1995)Acute childhood diarrhoea and maternal time allocation in the northern central Sierra of Peru Health Policy Plan 10(1): 60-70.

Bethony J, et al. (2006) Soil-transmitted helminth infections: ascariasis, trichuriasis, and hookworm. Lancet 367(9521): 1521-32.

Bhatia JC, Cleland J (1995) Self-reported symptoms of gynaecological morbidity and their treatment in South India. Studies in Family Planning 26(4): 203–16.

Biran A, Rabie T, Schmidt W, Juvekar S, Hirve S, Curtis V (2008) Comparing the performance of indicators of handwashing practices in rural Indian households. Trop Med Int Health 13: 278–285.

Biran A, Jenkins MW, Dabrase P, Bhagwat I (2011) Patterns and determinants of communal latrine usage in urban poverty pockets in Bhopal, India. Trop Med Int Health 16(7): 854–862. doi: 10.1111/j.1365-3156.2011.02764.x.

Birdthistle I, Dickson K, Freeman M, Javidi L (2011) What impact does the provision of separate toilets for girls at school have on their primary and secondary school enrolment, attendance and completion? A systematic review of the evidence. DFID. Available:http://www.dfid.gov.uk/R4D/PDF/Outputs/SystematicReviews/Birdthistle_Separate_toilets_for_girls_20110331.pdf . Accessed July 2011.

Black RE, Morris SS, Bryce J (2003) Where and why are 10 million children dying every year? Lancet 361(9376): 2226-34.

Black RE, et al. (2008) Maternal and child undernutrition: global and regional exposures and health consequences. Lancet 371(9608): 243-60.

Black RE, et al. (2010) Global, regional, and national causes of child mortality in 2008: a systematic analysis. Lancet 375(9730): 1969-87.

Bledsoe CH, Hill AG, Langerock P, D'Alessandro U (1994) Constructing natural fertility: the use of western contraceptive technologies in rural Gambia. Pop Develop Rev 20: 81–113.

Blencowe H, Cousens S, Mullany LC, Lee AC, Kerber K, Wall S, Darmstadt GL, Lawn JE (2011) Clean birth and postnatal care practices to reduce neonatal deaths from sepsis and tetanus: a systematic review and Delphi estimation of mortality effect. BMC Public Health **11**(Suppl 3): S11.

Blössner M, de Onis M (2005) Malnutrition: quantifying the health impact at national and local levels. Geneva: World Health Organization.

Blum D, Feachem RG (1983) Measuring the impact of water supply and sanitation investments on diarrheal diseases: problems of methodology. Int J Epidemiol 12: 357-365.

Bowen A, Ma H, Ou J, Billhimer W, Long T, Mintz E, Hoekstra R M, & Luby S (2007) A cluster-randomized controlled trial evaluating the effect of a handwashing-promotion program in Chinese primary schools. American Journal of Tropical Medicine & Hygiene, 76, 1166-73.

Briend A (1990) Is diarrhoea a major cause of malnutrition among the under-fives in developing countries? A review of available evidence. Eur J Clin Nutr 44(9): 611-628.

Brindha, K., R. Rajesh, et al. (2011) Fluoride contamination in groundwater in parts of Nalgonda District, Andhra Pradesh, India Environ Monit Assess 172(1-4): 481-492.

Briscoe J, Feachem RG, Raham MM (1985) Measuring the impact of water supply and sanitation facilities on diarrhea morbidity; prospects for case-control methods. Offset publication WHO/CWS/85.3. Geneva: World Health Organization.

Brooker S, Clements AC, Bundy DA (2006) Global epidemiology, ecology and control of soil-transmitted helminth infections. Adv Parasitol 62: 221-61.

Brooker S, Hotez PJ, and Bundy DA (2008) Hookworm-related anaemia among pregnant women: a systematic review. PLoS Neglected Tropical Diseases 2(9): e291. doi: 10.1371/journal.pntd.0000291 .

Brown JM, Proum S, Sobsey MD (2008) Escherichia coli in household drinking water and diarrheal disease risk: evidence from Cambodia. Water Sci Technol 58(4): 757-63.

Brown KH (2003) Diarrhea and malnutrition. J Nutr 133(1): 328-332.

Bulut A, Fillipi V, Marshal T, Nalbant H, Yolsal N, Graham W (1997) Contraceptive choices and reproductive morbidity in Istanbul. Stud Fam Plann 28: 35–43.

Burstrom B, et al. (2005) Equitable child health interventions: the impact of improved water and sanitation on inequalities in child mortality in Stockholm, 1878 to 1925. Am J Public Health 95(2): 208-16.

Burton MJ, Mabey DC (2009) The global burden of trachoma: a review. PLoS Negl Trop Dis 3(10): e460.

Cairncross S (1992) Sanitation and water supply: practical lessons from the decade. Water and Sanitation Discussion Paper 9. Washington DC: World Bank.

Cairncross S, Feachem R (1993) Environmental health engineering in the tropics (Second edition). Chichester: John Wiley & Sons.

Cairncross S, Shordt K, et al. (2005) What causes sustainable changes in hygiene behaviour? A cross-sectional study from Kerala, India Soc Sci Med 61(10): 2212-2220.

Cairncross S, Hunt C, Boisson S, Bostoen K, Curtis V, Fung IC, Schmidt WP (2010a) Water, sanitation and hygiene for the prevention of diarrhoea. Int J Epidemiol 39(1): 193-205.

Cairncross S, Bartram J, Cumming O, Brocklehurst C. (2010b) Hygiene, sanitation, and water: what needs to be done? PLoS Med Nov 16;7(11):e1000365.

Cairncross S, Kinnear J (1992) Elasticity of demand for water in Khartoum, Sudan. Soc Sci Med 34(2): 183-189.

Cairncross S, Valdmanis V (2006) Water supply, sanitation, and hygiene promotion. In: Disease Control Priorities in Developing Countries (2nd Edition). New York: Oxford University Press. 771-792.

Castro MC, et al. (2010) The importance of drains for the larval development of lymphatic filariasis and malaria vectors in Dar es Salaam, United Republic of Tanzania. PLoS Negl Trop Dis 4(5): e693.

Caulfield LE, de Onis M, Blössner M, Black RE (2004) Undernutrition as an underlying cause of child deaths associated with diarrhea, pneumonia, malaria, and measles. Am J Clin Nutr 80(1): 193-8.

Celik I Gallicchio L, et al. (2008)Arsenic in drinking water and lung cancer: a systematic review Environ Res 108(1): 48-55.

Chai PF, Lee WS (2009)Out-of-pocket costs associated with rotavirus gastroenteritis requiring hospitalization in Malaysia Vaccine 27 Suppl 5: F112-115.

Chatterjee L (2011) Time to acknowledge the dirty truth behind community-led sanitation. Posted on Guardian.co.uk 9/6/2011.
Chavasse D, Ahmad N, Akhtar T (1996) Scope for fly control as a diarrhoea intervention in Pakistan: a community perspective. Soc Sci Med 43(8): 1289-94.

Chavasse D, et al. (1999) Impact of fly control on childhood diarrhoea in Pakistan: community-randomised trial. Lancet, 353(9146): 22-5.

Checkley W, Buckley G, Gilman RH, Assis AM, Guerrant RL, Morris SS et al. (2008) Multi-country analysis of the effects of diarrhoea on childhood stunting. Int.J.Epidemiol 37: 816-30.

Chen Y,Ahsan H (2004)Cancer burden from arsenic in drinking water in Bangladesh Am J Public Health 94(5): 741-744.

Chen, Y., A. F. V. Geen, et al. (2007). "Reduction in urinary arsenic levels in response to arsenic mitigation efforts in Araihazar, Bangladesh." Environmental Health Perspectives **115**(6): 917-923.

Cheng T J, Ke DS, et al. (2010)The association between arsenic exposure from drinking water and cerebrovascular disease mortality in Taiwan Water Res 44(19): 5770-5776.

Chouhan S,Flora SJ (2010)Arsenic and fluoride: two major ground water pollutants Indian J Exp Biol 48(7): 666-678.

Churchill AA, de Ferranti D, Roche R, Tager C, Walters AA, Yazer A (1987) Rural water supply and sanitation: time for a change. World Bank Discussion Paper 18. Washington DC: World Bank.

Claeson M, Bos ER, Mawji T, Pathmanathan I (2000) Reducing child mortality in India in the new millennium. Bull World Health Organ 78: 1192-9.

Clasen T (2005) Household water treatment. WELL factsheet. Available: http://www.lboro.ac.uk/well/resources/fact-sheets/fact-sheets-htm/hwt.htm . Accessed July 2011.

Clasen TF, Bostoen K, Schmidt WP, Boisson S, Fung IC-H, Jenkins MW, Scott B, Sugden S, Cairncross S (2010) Interventions to improve disposal of human excreta for preventing diarrhoea. Cochrane Database of Systematic Reviews 6.

Clasen T, Schmidt WP, Rabie T, Roberts I, Cairncross S (2007) Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. BMJ 334(7597): 782.

Cohen D, et al. (1991) Reduction of transmission of shigellosis by control of houseflies (Musca domestica). Lancet 337(8748): 993-7.

Colwell, R.R., et al. (2003) Reduction of cholera in Bangladeshi villages by simple filtration. Proc Natl Acad Sci USA 100(3): 1051-5.

Coutsoudis A, et al. (2010) Women's morbidity and mortality in the first two years after delivery according to HIV status. AIDS 24(18): 2859-66.

Cowling BJ, Chan KH, Fang VJ, Cheng CK, Fung RO, Wai W, Sin J, Seto WH, Yung R, Chu DW, Chiu BC, Lee PW, Chiu MC, Lee HC, Uyeki TM, Houck PM, Peiris JS, Leung GM (2009) Facemasks and hand hygiene to prevent influenza transmission in households: a cluster randomized trial. Ann Intern Med 151(7): 437-46.

Cumming O, A Jeandron, J Ensink (2012) Trachoma & WASH: an evidence summary (prepared for DFID). SHARE: 2012.

Curtis V, Kanki B, Mertens T, Traore E, Diallo I, Tall F, Cousens S (1995) Potties, pits and pipes: Explaining hygiene behaviour in Burkina Faso. Soc Sci Med 41(3): 383-393

Curtis C (2005) Insecticide-treated nets against malaria vectors and polystyrene beads against Culex larvae. Trends Parasitol 21(11): 504-7.

Curtis C, Hawkins PM (1982) Entomological studies of on-site sanitation systems in Botswana and Tanzania. Trans R Soc Trop Med Hyg 76(1): 99-108.

Curtis C, Minjas J (1985) Expanded polystyrene for mosquito control. Parasitol Today 1(1): 36.

Curtis V, Cairncross S (2003) Effect of washing hands with soap on diarrhea risk in the community: a systematic review. Lancet
Infect Dis 3(5): 275–81.

Curtis V, Danquah L, Aunger R, (2009) Planned, motivated and habitual hygiene behaviour: an eleven country review. Health Education Research 24(4): 655-673.

Curtis VA, Garbrah-Aidoo N, Scott B (2007) Ethics in public health research: masters of marketing: bringing private sector skills to public health partnerships. Am J Public Health 97(4): 634-41. Epub 2007 Feb 28.

Curtis V, Schmidt W, Luby S, Florez R, Touré O, Biran A (2011) Hygiene: new hopes, new horizons. Lancet Infect Dis 11(4): 312-21.

Dangour AD, Watson L, Cumming O, Boisson S, Velleman Y, Cavill S, Allen E, Uauy R. (2011) Interventions to improve water quality and supply, sanitation and hygiene practices, and their effects on the nutritional status of children. Cochrane Database of Systematic Reviews 2011, Issue 10. Art. No.: CD009382. DOI: 10.1002/14651858.CD009382

Dar OA, Khan MS (2011) Millennium Development Goals and the water target: details, definitions and debate. Tropical Medicine and International Health 16(5): 540-544.

Dawney E, Shah H (2005) Behavioural Economics; Seven Principles for Policy-Makers. London: New Economics Foundation..

Deo DS (2007) Menstrual problems in adolescent school girls: A comparative study in urban and rural areas. Indian Journal of Preventive and Social Medicine. 38: 64-68.

Del Razo LM, Garcia-Vagras GG, et al. (2011) Exposure to arsenic in drinking water is associated with increased prevalence of diabetes: a cross-sectional study in the Zimapan and Lagunera Regions in Mexico. Environ Health 10(1): 73.

de Silva NR, Chan MS, Bundy DAP (1997) Morbidity and mortality due to ascariasis: re-estimation and sensitivity analysis of global numbers at risk. Tropical Med. Int. Health 2, 519–528.

Diaz-Villasenor, A., Burns AL, et al. (2007)Arsenic-induced alteration in the expression of genes related to type 2 diabetes mellitus. Toxicol Appl Pharmacol 225(2): 123-133.

DFID (1998) Guidance Manual for Water Supply and Sanitation Programmes. Loughborough: WELL for the Department for International Development. Available at: http://www.lboro.ac.uk/well/resources/Publications/guidance-manual/guidance-manual.htm. Accessed July 2011

DFID (2011) Research for Development: evidence papers. Available: http://www.dfid.gov.uk/r4d/evidencepapers.asp . Accessed July 2011.

Drank SDK, Uenkafa RP (1995). A study on menstrual hygiene among rural adolescent girls. Indian J Med Sci 45: 139 – 43.

Du Preez, M, RM Conroy, S Ligondo, J Hennessy, M Elmore-Meegan, A Soita, & KG McGuigan (2011) Randomized intervention study of solar disinfection of drinking water in the prevention of dysentery in Kenyan children aged under 5 years. Environmental Science and Technology, 9315. 45(21): p. 9315-9323.

Echeverria P, et al. (1983) Flies as a source of enteric pathogens in a rural village in Thailand. Appl Environ Microbiol 46(1): 32-6.

Edmunds WM, Smedley PL (2005) Fluoride in natural waters. In: Alloway BJ, Selinus O, eds. Essentials of medical geology. New York: Academic Press.

Emerson PM, et al. (1999) Effect of fly control on trachoma and diarrhoea. Lancet 353(9162): 1401-3.

Emerson PM, et al. (2004) Role of flies and provision of latrines in trachoma control: cluster-randomised trial. Lancet 363(9415): 1093-8.

Escamilla V, Wagner B, Yunus M, Streatfield PK, Van Geen A & Emch M (2011) Effect of deep tube well use on childhood diarrhoea in Bangladesh. Bulletin of the World Health Organization, 89, 521-7.

Esrey SA, Feachem RG, Hughes JM (1985) Interventions for the control of diarrheal diseases among young children: improving water supplies and excreta-disposal facilities. Bull World Health Organ 63(4): 757-772.

Esrey SA, Habicht JP (1986) Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. Epidemiol Rev 8: 117-28.

Esrey SA, Potash JB, Roberts L, Shiff C (1991) Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. Bull World Health Organ 69(5): 609-21.

Fakeye O, Egade A (1994) The characteristics of the menstrual cycle in Nigerian school girls and the implications for school health programs. Alrica J Med Sci 23: 13 – 4.

Feachem RG (1980) Rural water and sanitation. Community participation in appropriate water supply and sanitation technologies: the mythology for the Decade. Proc R Soc Lond B Biol Sci 209(1174):15-29.

Feachem RG, Burns E, Cairncross S, Cronin A, Cross P, Curtis D, Khalid Khan M, Lamb D, Southall H (1978) Water, health and development: an interdisciplinary evaluation. London: Trimed.

Feachem RG, Bradley D, Garelick H, Mara D (1983) Sanitation and disease: health aspects of excreta and wastewater management. Washington DC: John Wiley & Sons.

Fendorf, S., H. A. Michael, et al. (2010)Spatial and temporal variations of groundwater arsenic in South and Southeast Asia Science 328(5982): 1123-1127.

Fenn B, Bulti AT, Nduna T, Duffield A, Watson F. An evaluation of an operations research project to reduce childhood stunting in a food-insecure area in Ethiopia. Public Health Nutrition, Available on CJO 2012 doi:10.1017/S1368980012001115

Ferreccio C,Sancha AM (2006)Arsenic exposure and its impact on health in Chile. J Health Popul Nutr 24(2): 164-175.

Fekadu S, Yigzaw M, Alemu S, Dessie A, Fieldhouse H, Girma T, Trimble ER, Phillips DI, Parry EH (2010) Insulin-requiring diabetes in Ethiopia: associations with poverty, early undernutrition and anthropometric disproportion. Eur J Clin Nutr 64(10): 1192-8.

Fewtrell L, et al. (2005a) Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. Lancet Infect Dis 5(1): 42-52.

Fewtrell L, Fuge R, et al. (2005b) An estimation of the global burden of disease due to skin lesions caused by arsenic in drinking water J Water Health 3(2): 101-107.

Fewtrell L, Smith S, Kay D, Bartram J (2006) An attempt to estimate the global burden of disease due to fluoride in drinking water. J

Fewtrell L, Smith S, et al. (2006a) An attempt to estimate the global burden of disease due to fluoride in drinking water J Water Health 4(4): 533-542.Water Health): 533-42.

Fischer-Walker CL, Friberg IK, Binkin N, Young M, Walker N, Fontaine O, Weissman E, Gupta A, Black RE (2011) Scaling up diarrhea prevention and treatment interventions: A lives saved tool analysis. PLoS Med 8(3): e1000428.

Fonseca C, et al. (2011) WASHCost. Available: http://www.washcost.info/ . Accessed July 2011.

Foot S, Rashid H (2009) Governance of the water and sanitation sector in Bangladesh. London: DFID.

Fotedar R (2001) Vector potential of houseflies (Musca domestica) in the transmission of Vibrio cholerae in India. Acta Trop 78(1): 31-4.

Fotso JC, et al. (2007) Progress towards the child mortality Millennium Development Goal in urban sub-Saharan Africa: the dynamics of population growth, immunization, and access to clean water. BMC Public Health 7: 218.

Fritz V, Kaiser K, Levy B (2009) Problem driven governance and political economy analysis: good practice framework. Washington DC: World Bank.

Fung IC & Cairncross S (2006) Effectiveness of handwashing in preventing SARS: a review. Tropical Medicine & International Health, 11, 1749-58.

Fung IC & Cairncross S (2009) Ascariasis and handwashing. Trans R Soc Trop Med Hyg 103(3): 215-22.

Gaffga, N.H., R.V. Tauxe, and E.D. Mintz (2007) Cholera: A new homeland in Africa? American Journal of Tropical Medicine and Hygiene 77(4): p. 705-713.

Gardner R, Hamadani J, Grander M, Tofail F, Nermell B, Palm B, Kippler M & Vahter M (2011). Persistent exposure to arsenic via drinking water in rural Bangladesh despite major mitigation efforts. American Journal of Public Health, 101 Suppl 1, S333-8.

Geere JA, Hunter PR, Jagals P (2010) Domestic water carrying and its implications for health: a review and mixed methods pilot study in Limpopo Province, South Africa. Environ Health 26;9:52.

Giles DE, Mohapatra M, et al. (2011)Iron and aluminium based adsorption strategies for removing arsenic from water J Environ Manage.

Goldmann DA (2000) Transmission of viral respiratory infections in the home. Pediatr Infect Dis J 19: 97-102.

Guerrant RL, Kosek M, Lima AAM, Lorntz B, Guyatt HL (2002) Updating the DALYs for diarrhoeal disease. Trends Parasitol 18: 191–193.

Guerrant RL, Oriá R, et al. (2008) Malnutrition as an enteric infectious disease with long-term effects on child development. Nutrition reviews 66(9): 487-505.

Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, Schünemann HJ; GRADE Working Group (2008) GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 336(7650): 924-6.

Griffin SM, et al. (2011) Development of a multiplex microsphere immunoassay for the quantitation of salivary antibody responses to selected waterborne pathogens. J Immunol Methods 364(1-2) 83-93.

Gryseels B, Polman K, Clerinx J, Kestens L (2006) Human schistosomiasis. Lancet 368: 1106-18.

Han AM, Hlaing T (1989) Prevention of diarrhoea and dysentery by hand washing. Transactions of the Royal Society of Tropical Medicine and Hygiene 83: 128–131.

Harris JR, et al. (2009) Effect of a point-of-use water treatment and safe water storage intervention on diarrhea in infants of HIV-infected mothers. J Infect Dis 200(8): 1186-93.

Hill AB (1965) The environment and disease: association or causation? Proceedings of the Royal Society of Medicine. 58:295-300.Holl WH(2010)Mechanisms of arsenic removal from water Environ Geochem Health 32(4): 287-290.

Holmes J (2006) Do community factors have a differential impact on the health outcomes of boys and girls? Evidence from rural Pakistan. Health Policy Plan 21(3): 231-40.

Hoque BA, Mahalanabis D, Alam MJ, Islam MS (1995) Post-defecation handwashing in Bangladesh: practice and efficiency perspectives. Public Health 109: 15-24.

Hoque BA, Juncker T, Sack RB, Ali M, Aziz KM (1996) Sustainability of a water, sanitation and hygiene education project in rural Bangladesh: a 5-year follow-up. Bull.World Health Organ 74: 431-437.

Howard G, Ahmed MF, et al. (2006) Risk assessment of arsenic mitigation options in Bangladesh J Health Popul Nutr 24(3): 346-355.

Howard G, Ahmed MF, et al. (2007) Disease burden estimation to support policy decision-making and research prioritization for arsenic mitigation. J Water Health 5(1): 67-81.

Huicho L, Trelles M, Gonzales F (2006) National and sub-national under-five mortality profiles in Peru: a basis for informed policy decisions. BMC Public Health 6: 173.

Humphrey JH (2009) Child undernutrition, tropical enteropathy, toilets, and handwashing. Lancet 374(9694): 1032-5.

Huq A., et al. (2010), Simple sari cloth filtration of water is sustainable and continues to protect villagers from cholera in Matlab, Bangladesh. MBio, 1(1).

Hunt C, Lewin S (2000) Exploring decision-making for environmental health services: perspectives from four cities. Rev Environ Health 15(1-2): 187-206.

Hunter PR. (2009) Household water treatment in developing countries: comparing different intervention types using meta-regression. Environ Sci Technol 43(23): 8991-7.

Hunter PR, Zmirou-Navier D, Hartemann P (2009) Estimating the impact on health of poor reliability of drinking water interventions in developing countries. Science of the Total Environment 407: 2621-4.

Hunter PR, MacDonald AM, Carter RC (2010) Water Supply and Health. PLoS Med 7(11): e1000361. doi:10.1371/journal.pmed.1000361.

Hussain J, Hussain I, Sharma KC (2010) Fluoride and health hazards: community perception in a fluorotic area of central Rajasthan (India): an arid environment. Environmental Monitoring and Assessment 162: 1–14.

Hutton G, Bartram J (2008) Global costs of attaining the Millennium Development Goal for water supply and sanitation. Bull World Health Organ 86(1): 13-19.

Hutton G, Haller L (2004) Evaluation of the non-health costs and benefits of water and sanitation improvements at the global level. Geneva: WHO.

Hutton G, Haller L, Bartram J (2007) Global cost-benefit analysis of water supply and sanitation interventions. J Water Health 5: 481–502.

IRC (2007) Towards effective programming for WASH in schools: a manual on scaling up programmes for water, sanitation and hygiene in schools. TP series 48. Delft: IRC International Water and Sanitation Centre.

IRC (2009a) The sustainability and impact of school sanitation, water and hygiene education in Kenya. Delft: IRC International Water and Sanitation Centre.

IRC (2009b) The sustainability and impact of school sanitation, water and hygiene education in Kerala, Southern India. Delft: IRC International Water and Sanitation Centre.

Jain CK, Bandyopadhyay A, et al. (2010) Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand, India Environ Monit Assess 166(1-4): 663-676.

Jefferson T, Del MCB, Dooley L, Ferroni E, Al Ansary LA, Bawazeer GA, Van DML, Nair S, Jones MA, Thorning S & Conly JM (2011) Physical interventions to interrupt or reduce the spread of respiratory viruses. Cochrane Database of Systematic Reviews

Jenkins MW (1999) Sanitation promotion in developing countries: why the latrines of Benin are few and far between. PhD dissertation. UC Davis.

Jenkins MW, Sugden S (2006) Rethinking Sanitation: Lessons and Innovation for Sustainability and Success in the New Millennium. Thematic paper, UN Human Development Report 2006. Available at: http://hdr.undp.org/en/reports/global/hdr2006/papers/

Jia T-W, Melville S, Utzinger J, King CH, Zhou X-N (2012) Soil-Transmitted Helminth Reinfection after Drug Treatment: A Systematic Review and Meta-Analysis. PLoS Negl Trop Dis 6(5): e1621. doi:10.1371/journal.pntd.0001621

Jones, Finlay (2000) Sanitary towel provision and disposal in primary schools Child: Care, Health and Development Volume 27, No 1,

Joshi D, Fawcett B, Mannan F (2011) Health, hygiene and appropriate sanitation: experiences and perceptions of the urban poor Environment and Urbanization 23: 91-111.

Jukes MCH, Drake LJ, Bundy DAP (2008) Health, Nutrition and Education for All: Levelling the Playing Field. CABI Publishing, Wallingford.

Jüni P, Altman DG, Egger M (2001) Systematic reviews in health care: Assessing the quality of controlled clinical trials. BMJ 323(7303): 42-6.

Kahawita T (2009) Evaluation of the Effectiveness of Water, Sanitation, & Hygiene Interventions against Cholera. London School of Hygiene and Tropical Medicine: London.

Kapaj S,Peterson H, et al. (2006) Human health effects from chronic arsenic poisoning--a review J Environ Sci Health A Tox Hazard Subst Environ Eng 41(10): 2399-2428.

Kar K, Chambers, R(2008) Handbook on Community-Led Total Sanitation . London: Plan International (UK).

Katakura, K., Hamada, A. & Kobayashi, A. (1986). The fate of Ascaris eggs applied to the soil under various conditions. Japanese Journal of Parasitology, 35, 109

Khan M (1982) Interruption of shigellosis by handwashing. Trans R Soc Trop Med Hygiene 76: 164–68.

Khan WA, et al. (2004) Cryptosporidiosis among Bangladeshi children with diarrhea: a prospective, matched, case-control study of clinical features, epidemiology and systemic antibody responses. Am J Trop Med Hyg 71(4): 412-9.

Khin NO, Sebastian AA, Aye T (1989) Carriage of enteric bacterial pathogens by house flies in Yangon, Myanmar. J Diarrhoeal Dis Res 7(3-4): 81-4.

Khin MU, Myo K, Nyunt NW, Nyi WH, Thein TM, Butler TC (1994) Risk factors for persistent diarrhoea and malnutrition in Myanmar children. I: Socio-anthropological risk factors. J Trop Pediatr 40(1): 41-3.

Koenig MA, D'Souza S (1986) Sex differences in childhood mortality in rural Bangladesh. *Soc Sci Med* **22**: 15-22.

Koolwal G, van de Walle D (2010) Access to water, women's work and child outcomes. Washington DC: World Bank.

Kosek M, Bern C, Guerrant RL (2003) The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. *Bull World Health Organ* **81**(3): 197-204.

Kotloff KL, *et al.* (1999) Global burden of Shigella infections: implications for vaccine development and implementation of control strategies. *Bull World Health Organ* **77**(8): 651-66.

Lahariya C, Paul VK (2010) Burden, differentials, and causes of child deaths in India. *Indian J Pediatr* **77**(11): 1312-21.

Lanata CF (2003) Studies of food hygiene and diarrhoeal disease. *Int J Environ Health Res* **13**(1): 175-83.

Laxminarayan R, Chow J, Shahid-Salles SA (2006) Intervention cost–effectiveness: overview of main messages. In: Jamison DT, *et al.* eds. Disease Control Priorities in Developing Countries (2nd Edition) New York: World Bank/Oxford University Press.

Levine MM (2010) Immunogenicity and efficacy of oral vaccines in developing countries: lessons from a live cholera vaccine. *BMC Biol* **8**:129.

Liang S, Seto EYW, Remais JV, Zhong B, Yang C, Hubbard A, Davis GM, Gu X, Qiu D, Spear R (2007) Environmental effects on parasitic disease transmission exemplified by schistosomiasis in western China. *Proc Nat Acad Sci USA* **104**(17): 7110-7115.

Lima AA, Moore SR, Barboza MS, Jr., Soares AM, Schleupner MA, Newman RD *et al.* (2000) Persistent diarrhea signals a critical period of increased diarrhea burdens and nutritional shortfalls: a prospective cohort study among children in northeastern Brazil. *J Infect Dis* **181**:1643-51.

Loevinsohn BP (1990) Health education interventions in developing countries: a methodological review of published articles. *Int J Epidemiol* 19(4):788-94.Love DC, Sobsey MD (2007) Simple and rapid F+ coliphage culture, latex agglutination, and typing assay to detect and source track fecal contamination. *Appl Environ Microbiol* **73**(13): 4110-8.

Luby SP, Agboatwalla M, Feikin DR, Painter J, Billhimer W, Altaf A, Hoekstra RM (2005) Effect of handwashing on child health: a randomised controlled trial. *Lancet* **366**(9481): 225-233.

Luby SP, Agboatwalla M, Bowen A, Kenah E, Sharker Y, Hoekstra RM. (2009) Difficulties in maintaining improved handwashing behavior, Karachi, Pakistan. *Am J Trop Med Hyg* **81**(1):140-5.

Luby SP, Halder AK, Huda T, Unicomb L, Johnston RB (2011) The Effect of Handwashing at Recommended Times with Water Alone and With Soap on Child Diarrhea in Rural Bangladesh: An Observational Study. *PLoS Med* **8**(6): e1001052. doi:10.1371/journal.pmed.1001052.

Lucas, P. J., C. Cabral, *et al.* (2011)Dissemination of drinking water contamination data to consumers: a systematic review of impact on consumer behaviors *PLoS One* **6**(6): e21098.

Lule JR, Mermin J, Ekwaru JP, Malamba S, Downing R, et al (2005) Effect of home-based water chlorination and safe storage on diarrhea among persons with human immunodeficiency virus in Uganda. *Am J Trop Med Hyg* **73**: 926–933.

Lokuge KM, Smith W, Caldwell B, Dear K & Milton AH (2004) The effect of arsenic mitigation interventions on disease burden in Bangladesh. Environmental Health Perspectives, 112, 1172-7.

Luster MI, Simeonova PP (2004) Arsenic and urinary bladder cell proliferation *Toxicol Appl Pharmacol* **198**(3): 419-423.

Mai V, Draganov PV (2009) Recent advances and remaining gaps in our knowledge of associations between gut microbiota and human health. *World J Gastroenterol* **15**(1): 81-5.

Mai V, Young CM, Ukhanova M, Wang X, Sun Y, Casella G, Theriaque D, Li N, Sharma R, Hudak M, Neu J (2011) Fecal Microbiota in premature infants prior to necrotizing enterocolitis. *PLoS One* **6**(6):e20647.

Mahon T, Fernandes M (2010) Menstrual hygiene in South Asia: a neglected issue for WASH (water, sanitation and hygiene) programmes. *Gend Dev* **18**: 1, 99–113.

Mammen MP, Pimgate C, Koenraadt CJ, Rothman AL, Aldstadt J, Nisalak A, Jarman RG, Jones JW, Srikiatkhachorn A, Ypil-Butac CA, Getis A, Thammapalo S, Morrison AC, Libraty DH, Green S, Scott TW (2008) Spatial and temporal clustering of dengue virus transmission in Thai villages. *PLoS Med* **5**(11): e205.

Mara D, Lane J, Scott B, Trouba D (2010) Sanitation and Health. *PLoS Med* **7**(11): e1000363. doi:10.1371/journal.pmed.1000363 .

Mara DD (2000). The production of microbiologically safe effluents for wastewater reuse in the Middle East and North Africa. Water. *Air Soil Pollution* **123**: 595 – 603.

Marshall, G., C. Ferreccio, et al. (2007). "Fifty-Year Study of Lung and Bladder Cancer Mortality in Chile Related to Arsenic in Drinking Water." JNCI Journal of the National Cancer Institute **99**(12): 920-928.

Mascie-Taylor CG, *et al.* (1999) A study of the cost effectiveness of selective health interventions for the control of intestinal parasites in rural Bangladesh. *J Parasitol* **85**(1): 6-11.

Massey K (2011) MSc dissertation, London School of Hygiene & Tropical Medicine.

Maxwell CA, *et al.* (1999) Can vector control play a useful supplementary role against bancroftian filariasis? *Bull World Health Organ* **77**(2): 138-43.

Meliker JR, Wahl RL, *et al.* (2007) Arsenic in drinking water and cerebrovascular disease, diabetes mellitus, and kidney disease in Michigan: a standardized mortality ratio analysis *Environ Health* **6**: 4.

Miguel E, Kremer M (2004) Worms: identifying impacts on education and health in the presence of treatment externalities. *Econometrica* **72**: 159–217.

Million Death Study Collaborators (2010) Causes of neonatal and child mortality in India: A nationally representative mortality survey. *Lancet* **376** (9755): 1853-60.

MIRA Makwanpur trial team (2004) Effect of a participatory intervention with women's groups on birth outcomes in Nepal: cluster-randomised controlled trial. *Lancet* **364**(9438): 970-9.

Mitra AK, Rahman MM, Fuchs GJ (2000) Risk factors and gender differentials for death among children hospitalized with diarrhoea in Bangladesh. *J Health Popul Nutr* **18**:151-6.

Milton AH, Smith W, Dear K, Ng J, Sim M, Ranmuthugala G, Lokuge K, Caldwell B, Rahman A, Rahman H, Shraim A, Huang D & Shahidullah SM (2007). A randomised intervention trial to assess two arsenic mitigation options in Bangladesh. *Journal of Environmental Science & Health Part A-Toxic/Hazardous Substances & Environmental Engineering*, 42, 1897-908.

Moe CL, Sobsey MD, Samsa GP, Mesolo V (1991) Bacterial indicators of risk of diarrhoeal diseases from drinking-water in the Philippines. *Bull World Health Organ* **69** (3): 305-317.

Monteiro CA, *et al.* (2010) Narrowing socioeconomic inequality in child stunting: the Brazilian experience, 1974-2007. *Bull World Health Organ* **88**(4): 305-11.

Montgomery MA, Bartram J.(2010) Short-sightedness in sight-saving: half a strategy will not eliminate blinding trachoma. *Bull World Health Organ*88(2): 82.

Moraes LR, Cancio JA, Cairncross S (2004) Impact of drainage and sewerage on intestinal nematode infections in poor urban areas in Salvador, Brazil. *Trans R Soc Trop Med Hyg* **98**(4): 197-204.

Motarjemi Y, Käferstein F, Moy G, Quevedo F. (1993) Contaminated weaning food: a major risk factor for diarrhoea and associated malnutrition. *Bull World Health Organ.* **71**(1): 79-92.

Mozynski, P (2008) BMA says inadequate sanitation is a global crisis. *BMJ* 336(7636): 117.

Mukandavire Z, Liao S, Wang J, Gaff H, Smith DL, Morris JG Jr. (2011) Estimating the reproductive numbers fort he 2008-9 cholera outbreaks in Zimbabwe. *Proc Natl Acad Sci USA*. **108**(21): 8767-72.

Mukhtar M, *et al.* (2006) Importance of waste stabilization ponds and wastewater irrigation in the generation of vector mosquitoes in Pakistan. *J Med Entomol* **43**(5): 996-1003.

Nanan D, White F, Azam I, Afsar H, Hozhabri S (2003) Evaluation of a water, sanitation, and hygiene education intervention on diarrhoea in northern Pakistan. *Bull World Health Organ* **81**: 160-165.

Norman G, Pedley S, Bahi T (2010) Effects of sewerage on diarrhoea and enteric infections: a systematic review and meta-analysis.*Lancet Inf Dis* **10**(8): 536-544.

Norton DM, Rahman M, *et al.* (2009) Flocculant-disinfectant point-of-use water treatment for reducing arsenic exposure in rural Bangladesh. *Int J Environ Health Res* **19**(1): 17-29.

NRC (1999). Health Effects of Ingested Fluoride. Washington, DC, Subcommittee on Health Effects of Ingested Fluoride, National Research Council. http://books.nap.edu/catalog/2204.html

O'Lorcain P, Holland CV (2000) The public health importance of Ascaris lumbricoides. Parasitology 121, S51–S71.

O'Meally S (2009) Governance and drivers of change in Ethiopia's water supply sector. London: Overseas Development Institute.

O'Reilly CE, Freeman MC, Ravani M, Migele J, Mwaki A, Ayalo M, Ombeki S, Hoekstra RM, Quick R. (2008) The impact of a school-based safe water and hygiene programme on knowledge and practices of students and their parents: Nyanza Province, western Kenya, 2006. *Epidemiol Infect* **136**(1):80-91. Epub 2007 Feb 19.

Oster E,Thornton R (2009) *Menstruation and education in Nepal.* Unpublished.

Ozsvath, D. L. (2009). "Fluoride and environmental health: A review." Re-views in Environmental Science and Biotechnology **8**(1): 59-79.

Paoloni JDFiorentino CE, *et al.* (2003) Fluoride contamination of aquifers in the southeast subhumid pampa, Argentina. *Environ Toxicol* **18**(5): 317-320.

Pattanayak SK *et al.* (2010) How valuable are environmental health interventions? Evaluation of water and sanitation programmes in India. *Bulletin of the World Health Organization* **88**: 535-542. doi: 10.2471/BLT.09.066050

Petri WA Jr, *et al.* (2008) Enteric infections, diarrhea, and their impact on function and development. *J Clin Invest* **118**(4): 1277-90.

Pullan RL, Gething PW, Smith JL, Mwandawiro CS, Sturrock HJ, Gitonga CW, Hay SI, Brooker S (2011) Spatial modelling of soil-transmitted helminth infections in Kenya: a disease control planning tool. *PLoS Negl Trop Dis* **5**(2): e958.

Prüss A, et al (2002) Estimating the burden of disease from water, sanitation, and hygiene at global level. *Environ Health Perspect* **110**(5): 537-42.

Prüss A, Corvalan C (2006) Preventing disease through health environments. Geneva: World Health Organization.

Prüss-Üstün A, Corvalán C (2006) Preventing disease through healthy environments. Geneva: World Health Organization.

Prüss-Üstün A, Bos R, Gore F, Bartram J (2008) Safer water, better health: Costs, benefits and sustainability of interventions to protect and promote health. Geneva: World Health Organization.

Rabie T, Curtis V (2006) Handwashing and risk of respiratory infections: a quantitative systematic review. Trop Med Int Health 11(3): 258-67.

Rahman MM, Ng JC, *et al.* (2009) Chronic exposure of arsenic via drinking water and its adverse health impacts on humans. *Environ Geochem Health* **31** Suppl 1: 189-200.

Rice AL, Sacco L, Hyder A, Black RE (2000) Malnutrition as an underlying cause of childhood deaths associated with infectious diseases in developing countries. *Bull World Health Organ* **78**(10):1207-21.

Reed B, Harvey P (2004) Rural water supply in Africa: Building blocks for handpump sustainability. Loughborough: WEDC.

Rhee V, Mullany L, Khatry S, Katz J, *et al.* (2008) Maternal and birth attendant hand washing and neonatal mortality in southern Nepal. *Arch Pediatr Adolesc Med* **162**: 603–8

Rheingans RD, Constenla D, et al. (2007) Economic and health burden of rotavirus gastroenteritis for the 2003 birth cohort in eight Latin American and Caribbean countries. Rev Panam Salud Publica 21(4): 192-204.

Rheingans RD, Antil L, Dreibelbis R, Podewils LJ, Bresee JS, and Parashar UD (2009) Economic costs of rotavirus gastroenteritis and cost-effectiveness of vaccination in developing countries. Journal of Infectious Diseases 200: S16–S27.

Rosen S, Vincent J (1999). Household water resources and rural productivity in Sub-Saharan Africa: A review of evidence, Harvard Institute for International Development.

Rosen S, Vincent JR (2001) Household Water Resources and Rural Productivity in Sub-Saharan Africa: a Review of the Evidence. African Economic Policy Discussion Paper No. 69. Cambridge, Mass: John F. Kennedy School of Government, Harvard University.

Ross DA, Wight D, Dowsett G, Buve A, Obasi AI (2006) The weight of evidence: a method for assessing the strength of evidence on the effectiveness of HIV prevention interventions among young people. World Health Organ Tech Rep Ser 938: 79-102.

St. Louis ME, Porter JD, Helal A et al. (1990) Epidemic cholera in West Africa: the role of food handling and high-risk foods. American Journal of Epidemiology 131: 719-727.

Sandora TJ, Taveras EM, Shih MC, Resnick EA, Lee GM, et al (2005) A randomized, controlled trial of a multifaceted intervention including alcohol-based hand sanitizer and hand-hygiene education to reduce illness transmission in the home. Pediatrics 116(3): 587-594.

Schmidt WP, Cairncross S (2009) Household water treatment in poor populations: is there enough evidence for scaling up now? Environ Sci Technol 43(4): 986-92.

Schmidt WP, Aunger R, Coombes Y, Maina PM, Matiko CN, Biran A, Curtis V(2009a) Determinants of handwashing practices in Kenya: the role of media exposure, poverty and infrastructure. Trop Med Int Health 14: 1534-1541.

Schmidt WP, Cairncross S, Barreto ML, Clasen T, Genser B (2009b) Recent diarrhoeal illness and risk of lower respiratory infections in children under the age of 5 years. *Int J Epidemiol* **38**(3): 766-772.

Schmidt WP Schmidt WP, Boisson S, Genser B, Barreto ML, Baisley K, Filteau S, Cairncross S. (2010a) Weight-for-age z-score as a proxy marker for diarrhoea in epidemiological studies. *J Epidemiol Community Health* **64**(12): 1074-9.

Schmidt WP, Genser B, Barreto ML, Clasen T, Luby SP, Cairncross S, Chalabi Z. (2010b) Sampling strategies to measure the prevalence of common recurrent infections in longitudinal studies. *Emerg Themes Epidemiol* **7**(1): 5.

Schmidt WP, Suzuki M, Thiem VD, White RG, Tsuzuki A, Yoshida LM, Yanai H, Haque U, Tho LH, Anh DD, Ariyoshi K (2011) Population density, water supply and the risk of dengue fever in Vietnam: cohort study and spatial analysis. *PLoS Medicine* **8** (8), e10.

Scott BE, Schmidt WP, Aunger R, Curtis V, Garbrah-Aidoo N, Animashaun R (2008) Marketing Hygiene Behaviours: The Impact of Different Communications Channels on Reported Handwashing Behaviour of Women in Ghana. *Health Education Research* **23**(3):392-401.

Sedgwick WT, Macnutt S (1908) An examination of the theorem of Allen Hazen that for every death from typhoid fever avoided by the purification of public water supplies, two or three deaths are avoided from other causes. *Science* **28**: 215–216.

Sidibe M (2007) Can hygiene be cool and fun? Understanding school children's motivations to use their school toilets and wash their hands with soap in Dakar, Senegal. London: London School of Hygiene and Tropical Medicine.

Singh A (2008) Political economy reforms: learning from the Delhi water experience. Washington DC: World Bank.

Simoonga C, Utzinger J, Brooker S, Vounatsou P, Appleton CC, Stensgaard AS, Olsen A, Kristensen TK (2009) Remote sensing, geographical information system and spatial analysis for schistosomiasis epidemiology and ecology in Africa. *Parasitology* **136**(13): 1683-93.

Smith AH, Marshall G, Yuan Y, Ferreccio C, Liaw J, Ehrenstein OV, Steinmaus C, Bates MN & Selvin S (2006). Increased mortality from lung cancer and bronchiectasis in young adults after exposure to arsenic in utero and in early childhood. *Environmental Health Perspectives* 114, 1293-1296.

Smith, A. H. and C. M. Steinmaus (2009). Health effects of arsenic and chromium in drinking water: Recent human findings. Annual Review of Public Health. 30: 107-122p.

Snow, J (1855) On the mode of communication of cholera. London: Churchill.

Sohel, N., L. Å. Persson, et al. (2009). "Arsenic in Drinking Water and Adult Mortality: A Population-based Cohort Study in Rural Bangladesh." Epidemiology 20(6): 824-830.

Sohel N, Vahter M, Ali M, Rahman M, Rahman A, Streatfield PK, Kanaroglou PS & Persson LA (2010). Spatial patterns of fetal loss and infant death in an arsenic-affected area in Bangladesh. *International journal of health geographics*, 9, 53.

Stephenson LS, Latham MC, Ottesen EA (2000) Malnutrition and parasitic helminth infections. *Parasitology* **121**: 23-38.

Stevens GA, Dias RH, Ezzati M (2008) The effects of three environmental risks on mortality disparities across Mexican communities. *Proc Natl Acad Sci USA* **105**(44): 16860-5.

Strina A, Cairncross S, Barreto ML, Larrea C, Prado MS (2003) Childhood diarrhoea and observed hygiene behaviour in Salvador, Brazil. *Am J Epidemiol* **157**(11): 1032-1038.

Subaiya S, Cairncross S (2011) Response to Wang and Hunter: A systematic review and meta-analysis of the association between self-reported diarrheal disease and distance from home to water source. *Am J Trop Med Hyg* **84**(3):504; author reply 505.

Sullivan C,Tyrer M, *et al.* (2010) Disposal of water treatment wastes containing arsenic - a review *Sci Total Environ* **408**(8): 1770-1778.

Suthar S(2011) Contaminated drinking water and rural health perspectives in Rajasthan, India: an overview of recent case studies *Environ Monit Assess* **173**(1-4): 837-849.

Swatuk L (2008) A political economy of water in southern Africa. *Water Alternatives* **1**(1): 24-47.

Szostakowska B, *et al.* (2004) Cryptosporidium parvum and Giardia lamblia recovered from flies on a cattle farm and in a landfill. *Appl Environ Microbiol* **70**(6): 3742-4.

Talaat M, Afifi S, Dueger E, El-Ashry N, Marfin A, Kandeel A, Mohareeb E, & El-Sayed N (2011) Effects of hand hygiene campaigns on incidence of laboratory-confirmed influenza and absenteeism in schoolchildren, Cairo, Egypt. Emerging Infectious Diseases, 17, 619-25.

Tatem AJ, Smith DL (2010) International population movements and regional Plasmodium falciparum malaria elimination strategies. *Proc Natl Acad Sci USA* **107**(27): 12222-27.

Taylor MJ, Hoerauf A, Bockarie M (2010) Lymphatic filariasis and onchocerciasis. *Lancet* **376**(9747): 1175-85.

Thylefors B, Negrel AD, Pararajasegaram R, Dadzie KY (1995) Global data on blindness. *Bull World Health Organ* **73**:115-21.

Touré *et al.* 2011 In press.

Touré O (2009) Implementation of the Hazard Analysis Critical Control Points (HACCP) method to improve microbiological food safety in peri-urban Mali. PhD thesis, London School of Hygiene and Topical Medicine; 105.

UNICEF (2010) Progress for children: achieving the MDGs with equity. New York: UNICEF.

UNICEF/WHO (2009) Diarrhoea: Why children are still dying and what can be done. Geneva/New York: UNICEF/WHO.

UN Water 2008. International year of sanitation advocacy kit. Factsheet 3. Sanitation contributes to dignity and social development. Available: http://esa.un.org/iys/docs/IYS%20Advocacy%20kit%20ENGLISH/Fact%20sheet%203.pdf . Accessed July 2011.

Van de Poel E, O'Donnell O, Van Doorslaer E (2009) What explains the rural-urban gap in infant mortality: household or community characteristics? *Demography* **46**(4): 827-50.

Van Derslice J, Popkin B, Briscoe J(1994) Drinking-water quality, sanitation, and breast-feeding: their interactive effects on infant health. Bull World Health Organ. **72**(4):589-601.

Velema JP, Van Wijnen G, Bult P, Van Naerssen T, Jota S (1997) Typhoid fever in Ujung Pandang, Indonesia: high-risk groups and high-risk behaviours. *Tropical Medicine and International Health* **2**: 1088-1094.

Victora CG, Adair L, Fall C (2008) Maternal and child undernutrition: consequences for adult health and human capital. *Lancet* **371**: 340–57.

Victora CG, Smith PG, Vaughan JP, Nobre LC, Lombardi C, Teixeira AM, et al (1988) Water supply, sanitation, and housing in relation to the risk of infant mortality from diarrhea. *International Journal of Epidemiology* **17**(3): 651–54.

Vindigni SM, Riley PL, Jhung M. (2011) Systematic review: handwashing behaviour in low- to middle-income countries: outcome measures and behaviour maintenance. *Trop Med Int Health* **16**(4):466-77. doi: 10.1111/j.1365-3156.2010.02720.x. Epub 2011 Jan 12.

Wagner EG, Lanoix JN (1959) Water supply for rural areas and small communities. Geneva: World Health Organization.

Waddington H, Snilstveit B, White H, Fewtrell L (2009) Water, sanitation and hygiene interventions to combat childhood diarrhoea in developing countries. Synthetic review 1. New Delhi: 3ie.

Wang X, Hunter PR. (2010) A systematic review and meta-analysis of the association between self-reported diarrheal disease and distance from home to water source. *Am J Trop Med Hyg* **83**(3):582-4. Review.

Wang, C. H., C. K. Hsiao, *et al.* (2007) A review of the epidemiologic literature on the role of environmental arsenic exposure and cardiovascular diseases *Toxicol Appl Pharmacol* **222**(3): 315-326.

Wasserman, G. A., X. Liu, et al. (2004). "Water Arsenic Exposure and Children's Intellectual Function in Araihazar, Bangladesh." Environmental Health Perspectives **112**(13): 1329-1333.

Wasserman, G. A., X. Liu, et al. (2007). "Water arsenic exposure and intellectual function in 6-year-old children in Araihazar, Bangladesh." Environmental Health Perspectives **115**(2): 285-289

Wavde PN, Arjun B (2010)Groundwater quality assessment at Malegaon region of Nanded in Maharashtra (India) *J Environ Sci Eng* **52**(1): 57-60.

WaterAid (2011) Sustainability framework. London: WaterAid. Available: http://www.wateraid.org/documents/sustainability_framework_final.pdf . Accessed July 2011.

Wenneras C, Erling V (2004) Prevalence of enterotoxigenic Escherichia coli-associated diarrhoea and carrier state in the developing world. *J Health Popul Nutr* **22**(4): 370-82.

Whaley L, Webster J (2011) Effectiveness and sustainability of two demand-driven sanitation and hygiene approaches in Zimbabwe. *Journal of Water, Sanitation and Hygiene for Development* **1** 20–36.

White GF, Bradley DJ, White AU (1972) Drawers of water: domestic water use in East Africa. Chicago: University of Chicago Press.

Whittington D, Lauria DT, Okun DA, Mu X (1989) Water vending activities in developing countries. *International Journal of Water Resources Development* **5**(3): 158-168.

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

Williams, P. N., M. R. Islam, et al. (2006). "Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters." Environmental Science and Technology **40**: 4903-4908.

Wilson JM Chandler G (1993) Sustained improvements in hygiene behaviour amongst village women in Lombok, Indonesia. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. **87**(6): 615-616

Wood L, *et al*. (2008) Empirical evidence of bias in treatment effect estimates in controlled trials with different interventions and outcomes: meta-epidemiological study. *BMJ* **336**(7644): 601-5.

World Bank (1976) Measurement of the health benefits of investments in water supply. Report of an Expert Panel, Public Utilities Dept. Report no. PUN 20.

World Bank (1993) World Development Report 1993: Investing in Health. New York: Oxford University Press.

World Bank (2006) Repositioning nutrition as central to development. Washington DC: World Bank.

World Bank (2008) Environmental health and child survival: epidemiology, economics, experience. Washington DC: World Bank.

WHO (1983) Minimum evaluation procedure (MEP) for water and sanitation projects, in The International Drinking Water Supply and Sanitation Decade. WHO: Geneva.

WHO (1999) The Evolution of Diarrhoeal and Acute Respiratory Disease Control at WHO. WHO: Geneva <http://whqlibdoc.who.int/hq/1999/WHO_CHS_CAH_99.12.pdf.
Accessed: June 2011.

WHO (2001) Water-related diseases: typhoid and paratyphoid enteric fevers. Available from: http://www.who.int/water_sanitation_health/diseases/typhoid/en/ . Accessed July 2011.

WHO (2004) Water, sanitation and hygiene links to health: facts and figures. Available: http://www.who.int/water_sanitation_health/factsfigures2005.pdf . Accessed July 2011.

WHO (2005) Deworming for health and development: report of the third global meeting of the partners for parasite control. Geneva: WHO.

WHO (2008) Global burden of disease. Available from: http://www.who.int/evidence/bod . Accessed July 2011.

WHO (2009) Cholera: Prevention and Control. Available from: http://www.who.int/topics/cholera/control/en/index.html. Accessed July 2011 .

WHO (2010) Cholera fact sheet. Available from: http://www.who.int/mediacentre/factsheets/fs107/en/index.html . Accessed July 2011.

WHO (2010a) Weekly epidemiological record.WHO (2001) Water-related diseases: typhoid and paratyphoid enteric fevers. Available from: http://www.who.int/wer/2011/wer8631.pdfwater_sanitation_health/diseases/typhoid/en/. Accessed July 2011.

WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (2000) The global water supply and sanitation assessment 2000 report. Geneva, New York: WHO/UNICEF.

WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (2004) Meeting the MDG drinking-water and sanitation target: A mid-term assessment of progress. Geneva, New York: WHO/UNICEF.

WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (2008) Progress on drinking water and sanitation: special focus on sanitation. Geneva, New York: WHO/UNICEF.

WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (2010) Meeting the MDG drinking-water and sanitation target: A mid-term assessment of progress. Geneva, New York: WHO/UNICEF.

WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (2011) A snapshot of sanitation in South Asia with a focus on inequities. Available: http://www.wssinfo.org/fileadmin/user_upload/resources/SACOSAN-Final.pdf . Accessed July 2011.

WHO, UNICEF, UNESCO, World Bank, UNFPA, Education Development Center, Education International, Partnership for Child Development (2004) Skills for health: an important entry-point for health promoting/child-friendly schools. Geneva: WHO.

WSP (2011) The political economy of sanitation: how can we increase investment and improve service for the poor? WSP Sanitation Global Practice Team. Available: http://www.wsp.org/wsp/sites/wsp.org/files/publications/WSP-Political-Economy-of-Sanitation.pdf . Accessed July 2011.

Wu J, van Geen A, Ahmed KM, Alam YAJ, Culligan PJ, et al. (2011) Increase in Diarrheal Disease Associated with Arsenic Mitigation in Bangladesh. PloS ONE 6(12): e29593. doi:10.1371/journal.pone.0029593

Wutich A (2009) Intrahousehold disparities in women and men's experiences of water insecurity and emotional distress in urban Bolivia. *Med Anthropol Q* **23**(4): 436-54.

Yeager BA, Huttly SR, Bartolini R, Rojas M, Lanata CF (1999) Defecation practices of young children in a Peruvian shanty town. *Soc Sci Med* **49**: 531–541.

Young B, Briscoe J (1988) A case-control study of the effect of environmental sanitation on diarrhoea morbidity in Malawi. *J Epidemiol Community Health* **42**: 83-88.

Yuan, Y., G. Marshall, et al. (2007). "Acute myocardial infarction mortality in comparison with lung and bladder cancer mortality in arsenic-exposed region II of Chile from 1950 to 2000." American Journal of Epidemiology **166**(12): 1381-1391.

Zaroff B, Okun D A (1984) Water vending in developing countries. *Aqua* **5**, 289–295.

Annexes

Annex 1 – Search strings and inclusion criteria for systematic searches

The systematic literature searches were conducted using the OvidSP platform and the search terms are given below. From the results of the searches, a first selection was made on the content of the abstract and type of publication, and only peer-reviewed articles reporting interventional studies with a control arm or systematic reviews were included. The selection was then refined when full text was obtained.

General inclusion criteria were the following:

- **Population groups**, including:
  All; adults/ children; no setting restriction

- **Interventions/exposures**, including:
  Excreta-disposal interventions; water supply and water quality interventions; hygiene promotion (hand washing); and, where appropriate, vector control interventions

- **Outcomes**, including:
  Acute respiratory infections, intestinal parasitic infections, schistosomiasis, trachoma, arsenicosis and fluorosis

- **Study design**, including:
  Intervention studies, controlled, randomized or quasi-randomized

Search strings for each outcome are given below and the following databases were searched using OvidSP:

- Medline
- Cochrane
- Embase

The results for these searches are provided in Annex 2.
For under-nutrition the findings of a Cochrane Review on this subject the two of the authors of this paper were involved in were used. The full protocol has been published by Cochrane (Dangour et al 2011) and the results are reproduced in Annex 2.

		Total number of references retrieved in Medline, Global Health and Embase
	ARSENICOSIS	
1	exp Arsenic Poisoning/pc [Prevention & Control]	
2	(arsenic or arsenicosis).mp	
3	(prevention or mitigation or management or avoidance or removal).mp	
4	(Impact* or intervention* or trial* or effectiveness or efficacy).mp	
5	2 AND 3 AND 4	
6	1 OR 5 (limits "english", "after 1980", "humans")	589
	FLUOROSIS	
1	exp Fluoride Poisoning/pc [Prevention & Control]	
2	(fluoride or fluorosis).mp	
3	(prevention or mitigation or management or avoidance or removal).mp	
4	(Impact* or intervention* or trial* or effectiveness or efficacy).mp	
5	2 AND 3 AND 4	
6	1 OR 5 (limits "english", "after 1980", "humans")	1827
	SCHISTOSOMIASIS	
1	exp Schistosomiasis/pc [Prevention & Control]	
2	(schistosoma or schistosomiasis or schistosome$1).mp	
3	(infection or transmission).mp	
4	(prevention or control or management or elimination).mp	
5	(Impact* or intervention* or trial* or effectiveness or efficacy).mp	
6	2 AND 3 AND 4 AND 5	
7	1 OR 6 (limits "english", "after 1980", "humans")	3012
	INTESTINAL WORMS	
1	(ascaris or roundworm$1 or ascariasis or trichuris or whipworm$1 or trichuriasis or hookworm$1 or necator or ancylostoma or enterobius or enterobiasis or pinworm$1 or hymenolepis or hymenolepiasis or "dwarf tapeworm").mp	
2	((soil-transmitted or soil-borne or intestinal) adj1 (helminth$1 or helminthes or parasite$1 or worm$1 or nematode$1 or cestode$1)).mp	
3	(enteroparasit* or endoparasit* or geohelminth*).mp	
4	1 OR 2 OR 3	
5	((hygien$ adj3 (food or domestic or personal or education or promotion or behaviour)) or soap or handwashing or "hand washing").mp	
6	(toilet* or latrine* or pit or pits or Sanita* or (feces or faeces or fecal or faecal or excreta or waste) adj3 (disposal or management or service$1) or sewage or sewer$1 or sewerage or drainage).mp	
7	(Water adj2 (supply or availability or access or connect* or distance or improved or distribut* or quantity or volume)).mp	
8	5 OR 6 OR 7	
9	(Impact* or intervention* or trial* or effectiveness or efficacy).mp	
10	4 AND 8 AND 9 (limits "english", "after 1980", "humans")	439
	ACUTE RESPIRATORY INFECTIONS AND HANDWASHING	
1	Exp Respiratory Tract Infections/	
2	(ARI or acute respiratory infection$ or respiratory disease$ or respiratory symptom$ or respiratory illness$2).mp	
3	(Upper respiratory infection$ or URI or URTI or upper respiratory tract infection$ or lower respiratory infection$ or ALRI or LRI or LRTI or lower respiratory tract infection$).mp	
4	(common cold$ or sore throat or sinusitis or otitis or pharyngitis or influenza or pneumonia or sars or bronchitis or coryza or pertussis or epiglottitis or croup or whooping cough or bronchiolitis).mp	
5	1 OR 2 OR 3 OR 4	
6	exp handwashing/	
7	(handwashing or hand washing or hand cleaning or hand cleansing or hand hygiene).mp	
8	6 OR 7	
9	5 AND 8 (limits "english", humans", after 1980)	1522
	Trachoma	
1	toilet* OR latrine* OR pit OR pits OR Sanita*	
2	(feces OR faeces OR fecal OR faecal OR excre* OR waste) adj3 (disposal OR manag* OR service*)	
3	Water adj3 (supply OR availability OR access OR connect* OR distance OR improved OR distribut* OR quantity OR volume)	
4	handwashing OR facewashing OR (face* adj3 wash*) OR (hand* adj3 wash*) OR (eye* adj3 wash*) OR (clean adj2 face*) OR hygien*	
5	(fly OR flies OR musca OR sorbens OR vector) adj3 (control* OR manag* OR trap* OR spray* OR insecticid*)	
6	1 OR 2 OR 3 OR 4 OR 5	
7	trachom* OR sorbens	

8 Impact* OR intervention* OR trial* OR effectiveness OR efficacy
9 **6 AND 7 AND 8**

Annex 2 – Results for systematic searches

Childhood under-nutrition

Title	Date of publication	Authors	Intervention	Key outcomes of interest	Study design
A longitudinal study of the impact of behavioural change intervention on cleanliness, diarrhoeal morbidity and growth of children in rural Bangladesh. Social Science & Medicine	1993	Ahmed, N.U., et al.,	Hygiene promotion	Weight for age	Before and after
The Imo State (Nigeria) Drinking Water Supply and Sanitation Project, 2. Impact on dracunculiasis, diarrhoea and nutritional status	1990	Huttly, S.R.A., et al.,	Water supply	Weight for height	Quasi-experimental
Evaluation of a pre-existing, 3-year household water treatment and handwashing intervention in rural Guatemala	2009	Arnold, B., et al.,	Hygiene promotion & water treatment	Weight, height and MUAC	Prospective cohort with matched control
Lack of impact of a water and sanitation intervention on the nutritional status of children in rural Bangladesh.	1989	Hasan, K.Z., et al.	Water quantity/quality, sanitation and hygiene	Weight for age, height for age	Quasi-experimental
Randomized intervention study of solar disinfection of drinking water in the prevention of dysentery in Kenyan children aged under 5 years	2011	Du Preez, M., et al.,	Water treatment (SODIS)	Weight for age, height for age and weight for height	Randomised controlled trial
An evaluation of an operations research project to reduce childhood stunting in a food-insecure area in Ethiopia.	2012	Fenn, B., et al	Water supply, sanitation and hygiene	Height for age	Quasi-experimental
Nutrition and infection field study in Guatemalan villages, 1958-1964. VII. Physical growth and development of preschool children	1968	Guzman, M. A., N. S. Scrimshaw, et al	Sanitation and hygiene	height, weight, skinfold thickness, bone development	Proposective cohort with cross-sectional survey each 3 months
Hand-washing, subclinical infections, and growth: a longitudinal evaluation of an intervention in Nepali slums.	2011	Langford, R., P. Lunn,and C. Panter-Brick,	Hygiene promotion	Weight for height, height for age, weight for age, various bio-markers	Proposective cohort with cross-sectional survey each month
Environmental sanitation: a nutrition intervention	1983	Schlesinger, L., J. Weinberger, et al,	Sanitation	Weight (nutritional status)	Quasi-experimental

Intestinal parasitic infections

Title	Date of publication	Authors	Intervention	Key outcomes of interest	Study design
Impact of a citywide sanitation program in Northeast Brazil on intestinal parasites infection in young children	2010	BARRETO, M. L., GENSER, B., STRINA, A., TEIXEIRA, M. G., ASSIS, A. M. O., REGO, R. F., TELES, C. A., PRADO, M. S., MATOS, S. M. A., ALCANTARA-NEVES, N. M. & CAIRNCROSS, S	Sewerage improvement	Ascariasis and trichuriasis (prevalence only)	Before-after study
Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma.	1991	ESREY, S. A., POTASH, J. B., ROBERTS, L. & SHIFF, C.	Water supply and sanitation facilities improvement	Ascariasis and hookworm infections (prevalence and intensity of infection)	Systematic review
Ascariasis and handwashing	2009	FUNG, I. C.-H. & CAIRNCROSS, S.	Handwashing with or without soap promotion	Ascariasis (prevalence and intensity of infection)	Systematic review
The impact of improvement of water supply and sanitation facilities on diarrhea and intestinal parasites: a Brazilian experience with children in two low-income urban communities	1989	GROSS, R., SCHELL, B., MOLINA, M. C., LEAO, M. A. & STRACK, U.	Water supply and excreta disposal facilities improvement	Ascariasis and trichuriasis (prevalence only)	Cohort study
Effect of hygiene promotion on the risk of reinfection rate of intestinal parasites in children in rural Uzbekistan	2007	GUNGOREN, B., LATIPOV, R., REGALLET, G. & MUSABAEV, E.	Hygiene promotion (hand washing with soap, safe feces disposal and boiling drinking water)	Ascariasis reinfection rate after treatment	Before-after study with control gr
Impact of sanitation and health education on intestinal parasite infection among primary school aged children of Sherpur, Bangladesh	2003	HOSAIN, G. M. M., SAHA, S. & BEGUM, A.	Health education and latrine construction	Ascariasis and hookworm infections	Before-after study
Reviewing the health impacts of improvements in water supply	1997	LEWIN, S., STEPHENS, C. & CAIRNCROSS, S.	Water supply (quality and quantity) improvements alone or in combination with sanitation improvements	Ascariasis	Systematic review
Reductions in the prevalence and incidence of geohelminth infections following a city-wide sanitation program in a Brazilian Urban Centre	2010	MASCARINI-SERRA, L. M., TELLES, C. A., PRADO, M. S., MATTOS, S. A., STRINA, A., ALCANTARA-NEVES, N. M. & BARRETO, M. L.	Sewerage improvement	Ascariasis, trichuriasis and hookworm infection and incidence rates (prevalence and intensity)	Controlled cohort study
Environmental interventions and the pattern of geohelminth infections in Salvador, Brazil	2004	MORAES, L. R. S. & CAIRNCROSS, S.	Sewerage and drainage improvements	Ascariasis, trichuriasis and hookworm infection and reinfection rates (prevalence and intensity)	Longitudinal study
Effects of sewerage on diarrhoea and enteric infections: a systematic review and meta-analysis	2010	NORMAN, G., PEDLEY, S. & TAKKOUCHE, B	Sewerage improvements	Nematode infections	Systematic review
Evaluation of the effectiveness of deworming and participatory hygiene education strategy in controlling anemia among children aged 6-15 years in Gadagau community, Giwa LGA, Kaduna, Nigeria	2011	SUFIYAN, M., SABITU, K. & MANDE, A.	Participatory hygiene education	Nematode infections	Before-after study with control group
Effect of sanitation on soil-transmitted helminth infection: Systematic review and meta-analysis	2012	ZIEGELBAUER, K., SPEICH, B., MAUSEZAHL, D., BOS, R., KEISER, J. & UTZINGER, J.	Ownership and use of excreta disposal facilities	Ascariasis, trichuriasis and hookworm infections (prevalence only)	Systematic review

Acute Respiratory Infections

Title	Date of publication	Authors	Intervention	Key outcomes of interest	Study design
Effect of hand hygiene on infectious disease risk in the community setting: a meta-analysis.	2008	AIELLO, A. E., COULBORN, R. M., PEREZ, V. & LARSON, E. L.	Hand hygiene in community setting	Respiratory illnesses, school absenteism	Systematic review
Non-pharmaceutical public health interventions for pandemic influenza: an evaluation of the evidence base.	2007	ALEDORT, J. E., LURIE, N., WASSERMAN, J. & BOZZETTE, S. A.	Hand hygiene in healthcare and community setting during epidemic phase, with soap or hand sanitizer	Influenza	Systematic review
A cluster-randomized controlled trial evaluating the effect of a handwashing-promotion program in Chinese primary schools.	2007	BOWEN, A., MA, H., OU, J., BILLHIMER, W., LONG, T., MINTZ, E., HOEKSTRA, R. M. & LUBY, S.	Standard and intensive handwashing promotion	Respiratory disease incidence, school absenteism	Randomized controlled trial
Effectiveness of handwashing in preventing SARS: a review.	2006	FUNG, I. C.-H. & CAIRNCROSS, S.	Hand hygiene in healthcare and community settings	SARS infection	Systematic review
Physical interventions to interrupt or reduce the spread of respiratory viruses: systematic review.	2009	JEFFERSON, T., DEL MAR, C., DOOLEY, L., FERRONI, E., AL-ANSARY, L. A., BAWAZEER, G. A., VAN DRIEL, M. L., FOXLEE, R. & RIVETTI, A.	Handwashing with soap or hand sanitizer in healthcare and community settings	Viral respiratory infections	Systematic review
Physical interventions to interrupt or reduce the spread of respiratory viruses.	2011	JEFFERSON, T., DEL, M. C. B., DOOLEY, L., FERRONI, E., AL ANSARY, L. A., BAWAZEER, G. A., VAN, D. M. L., NAIR, S., JONES, M. A., THORNING, S. & CONLY, J. M.	Handwashing with soap or hand sanitizer in healthcare and community settings	Viral respiratory infections	Systematic review
Handwashing and risk of respiratory infections: a quantitative systematic review	2006	RABIE, T. & CURTIS, V.	Handwashing with soap or hand sanitizer in healthcare and community settings	Respiratory illnesses	Systematic review
Effects of hand hygiene campaigns on incidence of laboratory-confirmed influenza and absenteeism in schoolchildren, Cairo, Egypt	2011	TALAAT, M., AFIFI, S., DUEGER, E., EL-ASHRY, N., MARFIN, A., KANDEEL, A., MOHAREB, E. & EL-SAYED, N.	Hand hygiene promotion	Symptomatic and laboratory confirmed influenza-like illness, school absenteism	Randomized controlled trial

Arsenic and Fluorosis

Title	Date of publication	Authors	Intervention	Key outcomes of interest	
A sustainable community-based arsenic mitigation pilot project in Bangladesh	2001	ANSTISS, R., AHMED, M., ISLAM, S., KHAN, A. W. & AREWGODA, M.	Point-of-use arsenic removal system	Arsenic concentration in drinking water, users satisfaction	Pilot study (only 4 households)
Reduction in urinary arsenic levels in response to arsenic mitigation efforts in Araihazar, Bangladesh	2007	CHEN, Y., VAN GEEN, A., GRAZIANO, J. H., PFAFF, A., MADAJEWICZ, M., PARVEZ, F., HUSSAIN, A. Z. M. I., SLAVKOVICH, V., ISLAM, T. & AHSAN, H.	Well labeling, community information on unsafe water sources, installation of deep well where most needed	Well switching, urinary arsenic levels	Prospective cohort study
Effect of deep tube well use on childhood diarrhoea in Bangladesh	2011	ESCAMILLA, V., WAGNER, B., YUNUS, M., STREATFIELD, P. K., VAN GEEN, A. & EMCH, M.	Deep well installation	Diarrhoeal disease incidence in under 5-year-old	Prospective cohort study
Persistent exposure to arsenic via drinking water in rural Bangladesh despite major mitigation efforts.	2011	GARDNER, R., HAMADANI, J., GRANDER, M., TOFAIL, F., NERMELL, B., PALM, B., KIPPLER, M. & VAHTER, M	Multi-faceted arsenic mitigation strategy	Urinary arsenic levels, drinking water arsenic levels, food arsenic levels	Prospective cohort study
The effect of arsenic mitigation interventions on disease burden in Bangladesh	2004	LOKUGE, K. M., SMITH, W., CALDWELL, B., DEAR, K. & MILTON, A. H.	Multi-faceted arsenic mitigation strategy	Population-level exposure to arsenic	Burden of disease estimation
Dissemination of drinking water contamination data to consumers: A systematic review of impact on consumer behaviors	2011	LUCAS, P. J., CABRAL, C. & COLFORD JR, J. M.	Water consumers information on arsenic levels in their drinking water source	Water source switching	Systematic review
A randomised intervention trial to assess two arsenic mitigation options in Bangladesh.	2007	MILTON, A. H., SMITH, W., DEAR, K., NG, J., SIM, M., RANMUTHUGALA, G., LOKUGE, K., CALDWELL, B., RAHMAN, A., RAHMAN, H., SHRAIM, A., HUANG, D. & SHAHIDULLAH, S. M.	Provision of dug wells or three pitcher filters	Urinary arsenic levels, use of the provided mitigation solution	Randomized controlled trial
Flocculant-disinfectant point-of-use water treatment for reducing arsenic exposure in rural Bangladesh	2009	NORTON, D. M., RAHMAN, M., SHANE, A. L., HOSSAIN, Z., KULICK, R. M., BHUIYAN, M. I., WAHED, M. A., YUNUS, M., ISLAM, M. S., BREIMAN, R. F., HENDERSON, A., KESWICK, B. H. & LUBY, S. P.	Treatment with flocculant-disinfectant of tube wells	Urinary arsenic levels, arsenic level in tubewell water, fecal contamination of drinking water	Before-after study

Trachoma

Title	Date of publication	Authors	Intervention	Key outcomes of interest	Study design
Epidemiology and control of trachoma: systematic review	2010	**Hu et al**	SAFE	Active trachoma Severe trachoma	Systematic review
Face washing promotion for preventing active trachoma	2007	**Ejere at al**	Face-washing	Active trachoma Unclean faces Severe trachoma	Systematic review
Environmental sanitary interventions for preventing active trachoma	2007	**Rabiu et al**	Fly control Water supply Hygiene education	Active trachoma Fly density Latrine utilization Water utilization Adverse effects	Systematic review
Review of the evidence base for the "F" and "E" components of the SAFE strategy for trachoma control	2000	**Emerson et al**	F&E' of SAFE		Active trachoma Fly density Water availability & use Facial cleanliness Latrine coverage and utilization
Impact of face-washing and environmental improvement on reduction of active trachoma in Vietnam	2006	**Khandekar et al**	SAFE components vs SA components	Active trachoma Latrine presence, type and cleanliness Fly density Water supply type Compound cleanliness	Non-randomized 1:1 intervention study
How much is not enough? A community randomized trial of a water and health education programme for trachoma and ocular T. Trachomatis infection in Niger	2010	**Abdou et al**	Water supply and health education programme	Active trachoma T. Trachomatis infection	Randomized cluster controlled trial
Estimation of effects of community intervention with Antibiotics, Facial cleanliness, and Environmental improvement (A,F,E) in five districts of Ethiopia hyperendemic for trachoma	2010	**Ngondi et al**	All SAFE components	Active trachoma Unclean face Latrine coverage	Cross-sectional survey after 3 years of intervention
Efficacy of latrine promotion on emergence of infection with ocular Chlamydia trachomatis after mass antibiotic treatment: a cluster - randomized trial	2011	**Stoller et al**	Intensive latrine promotion after antibiotics mass treatment vs antibiotics mass treatment only	Active trachoma Ocular T. Trachomatis infection	Cluster-randomized controlled trial
Effects of interventions with the SAFE strategy on trachoma across Ethiopia	2011	**Roba et al**	All SAFE components	Trichiasis Active trachoma Unclean face No latrine use	Cross-sectional surveys conducted before and after 3 years of intervention

The Department for International Development:
leading the UK Government's fight against world poverty.

Department for International Development
22 Whitehall
London
SW1A 2EG
UK

and at:

Abercrombie House
Eaglesham Road East
Kilbride
Glasgow
G75 8EA
UK

Tel: +44 (0)20 7023 0000

Fax: +44 (0)20 7023 0016

Website: www. gov.uk/dfid

Facebook: www.facebook.com/ukdfid

Email: enquiry@dfid.gov.uk

Public enquiry point: 0845 3004100 or +44 1355 84 3132 (if you are calling from abroad)

Published by the Department for International Development, May 2013