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Public Health and Social Benefits of at-house Water Supplies

Final Report

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List of abbreviations

CFU	Colony-forming Unit
CI	Confidence interval
DFID	UK Government Department for International Development
DRC	Democratic Republic of Congo
E.Coli	Escherichia coli
GH	Ghana
GLAAS	UN-Water Global Analysis and Assessment of Sanitation and Drinking Water
JMP	Joint Monitoring Programme for Water Supply and Sanitation
km	Kilometre
L95%CI	Lower 95% confidence Interval
l	Litre
lpcd	Litres per capita per day
m	Metre
min	Minute
ml	Millilitre
SA	South Africa
SD	Standard deviation
U95%CI	Upper 95% confidence interval
UNICEF	United Nations Children's Fund
V	Vietnam
WHO	World Health Organisation

Executive summary

We carried out a mix of secondary and primary research to examine the hypothesis that access to an at-house water supply will deliver significantly greater health, social and economic benefits than those derived from a shared public water supply. Our research was based on a mix of literature review and field-base case studies. Fieldwork was carried out in three countries; Ghana, South Africa and Vietnam and used a mix of data collection methods, specifically a three-part household questionnaire, which included anthropometric measures and the measurement of water collection journeys, natural group discussions, and contextual checklists.

The relationship between water source, water usage and health and social outcomes is complex and mitigated by a range of contextual and intermediate factors. A fundamental challenge in comparing outcomes of at-house supplies with shared supplies lies with wealth as a confounder. In our analysis we were able to account for wealth effects to some extent because of the detailed household information we were able to collect. Nonetheless these challenges are significant.

In our research we focused on a two-step approach, looking at the relationship between distance to source and volumes of water consumed followed by an analysis of volumes of water carried/consumed and the health and social outcomes including hygiene practices. In this way we reduced the effect of wealth and other broader social contextual factors in the analysis. This was supplemented by the analysis of the relationship between source-type and water quality.

From our field data a strong theme was that households often used multiple water sources. This dimension of water usage has received only limited attention from researchers. It is likely that the use of multiple sources of water for different activities is a significant confounder and one of the reasons why research into the relationships between health outcomes and use of specific water sources has been inconclusive.

We found a strong link between volumes of water consumed and the at-home-off-plot break point in services, but limited evidence of a distance-volume relationship once households were using off-plot supplies. We also found some evidence to suggest that where reliability of services is poor, the location of the water source may be less significant than its performance characteristics. In our study locations we found some evidence of households who access water from both private and public wells collecting higher quantities of water than users who access water from taps. Similarly we found strong evidence of a ‘break point’ in health outcomes between those who carried or who had previously carried water from outside the house and those who did not, relating to musculo-skeletal effects. Water quality was significantly better for those with piped water at home than those who carried water from elsewhere and stored it at home. The evidence on social benefits was limited but points to possible advantages to families who do not have to spend time carrying water but can spend time in leisure activities.

Overall the results from our research indicate that evidence for the detailed water quantity versus distance to source curve previously suggested is tenuous. The conclusion that at-house supplies are associated with higher consumption and health and social benefits is supported, but there is no evidence for the secondary drop in consumption at a fixed distance from home. In reality it seems most likely that the relationship between distance to source and volumes of water consumed is highly mediated by social and geographical factors. This suggests the quantity-distance curve is likely to be ‘displaced’ upwards or downwards in different contexts.

The headline conclusion from our research is that at-home water supply has significant, measurable benefits when compared with shared water supply outside the home provided that the service provided is reliable enough to ensure access to adequate quantities of water when required. Reliable at-home water supply results in higher volumes of water consumed, greater practice of key hygiene behaviours, a reduction in musculo-skeletal impacts associated with carrying water from outside the home, and

improved water quality. This suggests a logical policy shift towards the promotion of reliable household access as the international benchmark for water supply.

For many governments, the implications of this are relatively simple. Where most people have access to reasonable quantities of water close to the home, there is a strong and compelling argument to focus investment in getting reliable water supplies into the home. In such cases, the outstanding challenges relate to improving our understanding of the relative risks associated with different dimensions of levels of service. For example, under what circumstances does a tap in the house have significant benefits over a tap in the yard? What is the relative risk associated with intermittent supply or low pressure of at-house piped supplies compared with private wells or shared supplies, if the latter can provide a more reliable service? A pressing gap in the literature relates to the water resources and cost implications of providing 24 hour supply in piped systems.

For some countries however, the challenge of moving to household supply as the benchmark level of service is more significant and will take time. In these locations (typically arid regions with limited water resources and limited access to capital funds) the policy emphasis may change more slowly. The clear policy message is that investments in water supply should be designed to enable a progressive move towards provision of household supplies even if this level of service cannot be achieved immediately. This might mean for example, designing point-source systems in such a way as to facilitate the addition of networks and house connections at a later date.

In the post-2015 era, the available evidence suggests that access to reliable water supply at home should be the benchmark for water supply.

1. Background

1.1. Research aims and objectives

This research project aimed to test the hypothesis that an at-house water supply will deliver significantly greater health, social and economic benefits than those derived from a shared public water supply.

Three primary research questions drove the research to test this hypothesis:

1. What are the patterns of water usage including quantities used and purposes in relation to a range of source types, reliability of service and distance?
2. What health outcomes are associated with different levels of water supply provision?
3. What are the socio-economic benefits derived from different levels of water supply provision?

1.2. The team

The project team comprised researchers in water and health from five Universities:

- the water@leeds team at the University of Leeds;
- the Water Institute at the University of North Carolina;
- the University of East Anglia
- the London School of Hygiene and Tropical Medicine; and
- the University College London.

The team benefited greatly from collaborations with numerous colleagues who supported out work in the field in Ghana, South Africa and Vietnam. Their contributions have been significant and they will play a major role and be fully acknowledged in the publication of the findings from this study.

1.3. The approach

The project utilised several methods to test the study hypothesis. Broadly these can be defined as:

- a review of both scientific and grey literature;
- a review of existing analysis of secondary global data to explore associations between levels of water service, quality of service and health outcomes;
- Field studies utilising qualitative and quantitative fieldwork, data collection and analysis in three countries.

1.4. This report

This report is the final report and summarises the results of both the secondary literature-based research and the field work. Further publications that will appear in open access Journals are planned on the basis of this work. A summary publication plan is included at the end of the report.

2. Methodology

2.1. Literature reviews

We carried out four reviews of the existing literature. The first was a systematically-organised review of the relationship between distance to source and quantities of water consumed. The results are described in Section 3.3.1. The second was a systematically-organised review of the health benefits of at-house water supplies. The results are described in section 3.4.1. We also carried out two brief reviews of the impacts of at-house water supplies on hygiene activities in the home, and the impact of water carrying on musculo-skeletal health impacts. These results are reported in sections 3.4.2 and 3.5.1. One of our team members (UNC) also conducted, at the time of this work, and primarily funded by WaterAid, a review of literature concerning the water quality of different facility types including at-home and off-plot supplies. We summarise that work in Section 3.6.23.6.2.

2.2. Field-based studies

2.2.1. Selection of field research locations

We carried out field research in three countries; South Africa, Ghana and Vietnam. Details of the field studies are given in **Appendices 1,2 and 3**. Case studies were selected to provide a range of contexts but are not representative of the countries in which they were carried out or designed to be globally representative. This research project was not large enough to accommodate representative sampling; our approach was to identify a range of cases which would provide insights into household behaviours and outcomes associated with a range of types of water source, quality of water services and topography.

In Ghana our research was conducted in four communities near Kumasi in the Ashanti region. All four communities were centred around a main road, stretching out densely along the road and less densely outward from the road on either side and could broadly be defined as urban or peri-urban. Water was supplied through a combination of private taps, public taps and private boreholes. The purchase of 'sachet' water was relatively common.

In Vietnam our research was conducted in the remote rural Lao Cai province. Lao Cai is a mountainous area. The communities in Lao Cai were generally small scattered rural hamlets and ethnically heterogeneous. Most households accessed water from several sources, some including piped water supply to the home, private boreholes and dug wells, and public springs.

In South Africa we carried out fieldwork in three peri-urban communities in Vhembe District in the northern parts of Limpopo Province. Two communities were located in the dry, flat area west of Makhado/ Louis Trichardt town. The water sources here were communal taps or private drilled wells with either a yard tap or in-house connection. The third community was located in the foothills of the Soutpansberg mountain range. Shared water sources in the area are protected springs and communal taps, while some households had yard-taps or in-house taps.

2.2.2. Data collection tools

Two hundred households were recruited to participate in the study in each country. Stratified random sampling was used to recruit a mix of household with at-house and shared water supplies. In each community three data collection tools were used; the household questionnaire, natural group discussions[1] and a community contextual checklist. The latter was used to capture non-water supply characteristics of the community such as environmental conditions, availability of sanitation and prevalence of open defecation.

The household questionnaire was divided into three parts. Part 1 was administered to all households and investigated sources of water used, water usage patterns and health outcomes. Part 2a was administered to one member of each household who was a water carrier to understand water carrying practices and health outcomes. Part 2b was administered to sub-set of water carriers and involved following the water carrier using a GPS tracker to ascertain exact distances and times involved in water collection activities. In Ghana and South Africa Part 2b was administered to all households, in Vietnam a

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[1] Natural group discussions, as compared to focus group discussion with which readers may be more familiar, are carried out with a group of participants who naturally gather together rather than with a group that is purposively selected. They are not representative of the population as a whole, but rather allow people to come together in groups where they feel comfortable to express their views freely.

sample of 10% of water carriers were recruited to participate in Part 2b of the questionnaire.

2.2.3. Fieldwork protocol and ethical approval

The fieldwork was driven by a protocol prepared by the field teams prior to travelling to the field. The protocol was prepared and tested at a project workshop in June 2012 prior to the fieldwork activities which were carried out between June and October 2012. Fieldwork tools were also separately piloted in all three project locations. In each case data collection tools were first translated into the appropriate local language and then back-translated prior to piloting. Fieldwork was staggered so that the first field-based pilot in Ghana could used to make overall modifications to the protocol where required. Subsequent piloting in Vietnam and South Africa was then used to make local adjustments as required.

Ethical approval for fieldwork, including data management strategies, was obtained by the University of Leeds covering work undertaken in Vietnam by Leeds researchers and in South Africa by researchers from UEA. Separate ethical approval was obtained from the University of North Carolina for fieldwork carried out by their researchers in Ghana.

3. Results

3.1. Definitions of access and the experience of households in our field studies

3.1.1. Global definitions of "access"

Conceptually, water services can be described in terms of the source and means of abstraction of the raw water; the nature of the reticulation / distribution system to consumers; and the patterns of use of the supplied water (Merrett, 2002). Water supply system performance can be categorised according to a number of different criteria. The choice of criteria depends on the local policy and service provision norms, which in turn may be based on the sociological, cultural, economic, natural and environmental background. Except in systems where universal access is provided by means of at-house piped supplies, water supply services are commonly described by sector professionals according to the type of technology used, distance to water source for users, quantity of water available and the quality of the water provided.

One of the targets of the Millennium Development Goals is "to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation." The Joint Monitoring Program (JMP) is the official interagency UN mechanism tasked with measuring progress towards achieving the MDGs and is a collaboration between the World Health Organization (WHO) and UNICEF. Table 1 below sets out the technologies considered 'improved' and those considered 'unimproved' by the JMP. In March 2012, WHO and UNICEF announced that the MDG water target had been met, with over 88% of the world's population having access to an improved drinking water source. For the purposes of estimated progress towards achieving the target, JMP "has established a standard set of categories that are used to analyse national data on which the MDG trends and estimates are based"JMP (2012).

Howard and Bartram, in their 2003 review of the evidence on water quantity noted that a 'basic' level of water consumption of up to 20 litres per capita per day (lpcd) is likely to be sufficient for basic health protection but would still leave inadequate quantities of water for "effective use in hygiene practices". They estimated that around 7.5 litres of this water would typically be required for direct consumption (although the amount would vary with ambient temperatures, typical work patterns and a range of other factors) (Howard and Bartram, 2003). Twenty litres per capita per day has now been internationally recognised as a benchmark consumption figure; it is directly referenced in General comment 15 on the Human Right to Water. As it is currently infeasible to measure water consumption reliably at the household level distance (or time) to water source is often proposed as a proxy indicator for consumption quantities.

Table 1: Definitions of improved and unimproved drinking water sources

Improved drinking water	**Unimproved drinking water**
Use of: • Piped water into dwelling, yard of plot • Public tap or standpipe • Tubewell or borehole • Protected spring • Protected dug well • Rainwater collection	Use of: • Unprotected dug well • Unprotected spring • Cart with small tank or drum • Tanker truck • Surface water (river, dam, lake, pond, stream, canal, irrigation channel) • Bottled water (considered to be improved only when the household uses drinking water from an improved source for cooking and personal hygiene)

Since 2000 ‘reasonable access’ to water supply has been interpreted by JMP as “the availability of at least 20 litres per person per day from a source within one kilomet[re] of the user’s dwelling” JMP (2000). According to the most up to date WHO information “Access to drinking water means [for the JMP] that the source is less than 1 kilomet[re] away from its place of use and that it is possible to reliably obtain at least 20 litres per member of a household per day” (WHO, 2013).

The origin of the 1 kilometre (km) break point distance comes from studies conducted during the 1970s and 1980s in sub-saharan Africa by White et al. (1972), Feacham (1978) and Cairncross and Cliff (1987). According to these studies, there is a plateau effect of per capita water usage at the household when the water collection time from house to source is between 5 to 30 minutes and then a substantial decline occurs for households whose collection time to a water source exceeds 30 minutes (See Figure 1). The curve shown in Figure 1 is often referred to as the ‘Bradley curve’ as it draws heavily on work carried out by Bradley and collaborators looking at water usage in Africa in the early 1970s (White et al. (1972). A round trip time of 30 minutes is approximately equal to a distance of 1 km home to source assuming no waiting time at the tap (Cairncross (1987)).

Evidence for a relationship between 1 km distance and 20 lpcd consumption is extremely difficult to find. Furthermore, since JMP estimates rely on data collected from a range of household surveys, it is not clear that the distance parameter is reliably applied across all the estimates. Recent updates of the JMP estimates do not for example refer to distance when describing access to water supply.

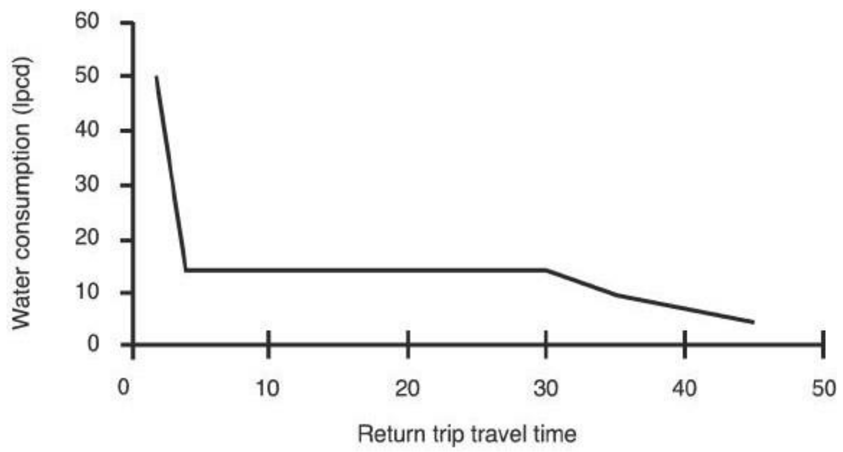

Figure 1: Graph of relationship between travel time (minutes) and water consumption (lpcd)

Source: (Cairncross, 1987)

3.1.2. National definitions of "access"

From a policy perspective both international and national definitions and their use in monitoring are important. In general things that are measured tend to be prioritised over things which are not measured; the degree to which distance is used by national monitoring systems provides a useful insight into the potential policy implications of the research findings of this study.

To establish the extent to which countries use distance as a way to define access to water supply and also to understand how widespread is the use of JMP definitions we carried out a brief review of how countries define access to water supply. To do this we reviewed the country responses to the 2011 UN-Water Global Analysis and Assessment of Sanitation and Drinking Water (GLAAS) country survey (GLAAS (2011). The questionnaire calls on countries to describe how they define 'adequate' water supplies and how this information is collected.

A total of 75 countries submitted returns to the 2011 survey. Of these six did not answer the question relating to definition of 'adequate' water supply (Table 2).

Of the the 69 countries who did return a definition, 61 use technology as one dimension of their definition (Figure 2). Of these, 48 (79% of those using technology definitions) include protected wells, 47 (77%) boreholes/ tubewells, usually with a motor or manual pump, and 33 (54%) include springs (usually defined as 'protected' springs). Eight countries (13% of those using technology in the definition) include all the technologies which are described as 'improved' in the JMP method. These countries are; Bangladesh, Bhutan, the Democratic Republic of the Congo (DRC), Indonesia, Myanmar, Nepal, Pakistan and Sri Lanka. DRC explicitly states that JMP categories of improved water supply will be used. Four countries (7% of those using technology in the definition) only include at-house taps in the measure of access to water supply and these countries are Dominican Republic, Egypt, Iran and Jordan.

The countries which do *not* use technology in their definition are: Ethiopia, Fiji, Maldives, Samoa, South Africa, Tajikistan, Uzbekistan and Vietnam. Vietnam is alone in describing allowable management arrangements for water supply rather than technology or levels of access.

The country with the most comprehensive description of access is the Philippines which describes three levels of service in terms of distance, number of users and type of technologies.

Table 2: Countries responding to the 2011 UN-Water GLAAS country survey

Region	Countries returning access definitions	Countries not returning access definitions
Caucasus and Central Asia	Azerbaijan, Kyrgyztan, Tajikistan, Uzbekistan	
Eastern Asia	Mongolia	
Latin America and the Caribbean	Bolivia, Brazil, Dominican Republic, El Salvador, Honduras, Panama, Paraguay	Colombia, Haiti
Southeastern Asia	Cambodia, Indonesia, Lao PDR, Myanmar, Philippines, Thailand, Vietnam	Timor L'Este
South Asia	Afghanistan, Bangladesh, Bhutan, India, Iran (Islamic Republic of), Maldives, Nepal, Pakistan, Sri Lanka	Afghanistan
Sub Saharan Africa	Angola, Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, DRC, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Rwanda, Samoa, Senegal, Sierra Leone, South Africa, Sudan, Togo, Uganda, Zimbabwe	South Sudan
Western Asia	Jordan, Lebanon, Yemen	Oman

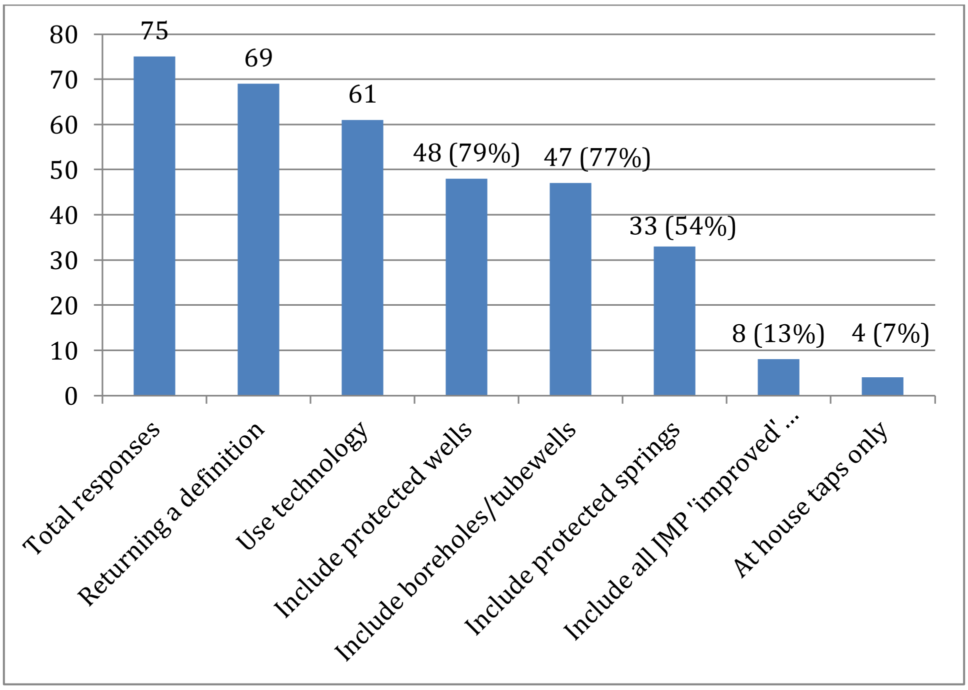

Figure 2: Countries using technology in national definitions for water supply

Nine countries include distance to source as part of their definition; in most cases the distance is considerably less than the 1 km suggested by Cairncross, while Ethiopia counts sources 1.5 km from home in rural areas. The full list of these countries is shown on Table 2. Only one country, Liberia, includes a measure of time to source (within 10 minutes). Six countries use number of users as one measure of access to services for some technologies (Table 4). Eighteen countries have water quality as part of the definition of access (Table 5).

Table 3: Countries using distance to source in their definition

	Technology	Distance to source (m)
Rural and Urban		
Dominican Republic	Private tap	500
Philippines	Point sources (Level 1)	25
Philippines	Shared taps (Level 2)	250
Sri Lanka	Multiple	200
Malawi	Multiple	500
Nigeria	Multiple	250
South Africa	Not specified	200
Rural alone		
Morocco	Public tap	500
Ethiopia	Not specified	1500
Rwanda	Multiple	500
Urban alone		
Morocco	Public tap	200
Ethiopia	Not specified	500
Rwanda	Multiple	200

Table 4: Countries using number of users in their definition

	Type of technology	Nr of Users/ Unit
Rural and Urban		
Egypt	Private tap	Apartment
Bangladesh	Private tap	5
Bangladesh	Public tap	100
Mozambique	Private tap	5
Mozambique	Well/ borehole	500
Rwanda	Public tap or borehole with motor	300
Rwanda	Borehole with handpump	350
Rural only		
Benin	Public tap	250
Guinea-Bissau	Well/ borehole	150
Urban only		
Benin	Public tap	12

Table 5: Countries including water quality in the definition

Country	Water quality standards/ commentary
Ethiopia, Fiji, Rwanda	World Health Organisation standards
Indonesia	Source should be more than 10m from sewage disposal point
El Salvador	Treatment
Dominican republic	Treated and chlorinated
South Africa, Mongolia, Tajikistan, Lesotho, Jordan, India	National standards
Samoa	National standards (in line with EU standards)
Honduras	Protected from fecal contamination
Congo, Morocco	Potable
Maldives	Boiled, treated or chlorinated or desalinated water
Panama	Filtered and disinfected

The specific definitions used in our three study countries are summarised below in Table 6.

Table 6: Minimum criteria for 'basic' water services in Ghana, South Africa and Vietnam

	Ghana	South Africa	Vietnam*
Level	'basic'	'basic'	-
Source	'improved'	tap	-
Density (people per water source)	300 (hand-pump)	-	-
Distance (m)	500	200	-
Quantity (ℓ)	20	25	-
Quality	National standards	National standards	-
Flow rate (ℓ/min)	-	10	-
Reliability	95%	98%	-

*Vietnam defines access to water supplies as those provided through approved institutional arrangements

We can see therefore that definitions of level of service in most countries focus on technology (see also (O'Hara et al., 2008)); issues of reliability and flow rate/pressure are rarely considered and some commentators have observed that they are considered to be of secondary importance (Hope and Garrod, 2004). For water users however the functionality or performance of the supply may be very important (Gulyani et al., 2005). Thus, while a tap in the house may, in theory, provide a higher level of service than a yard tap or communal standpipe, low pressure or intermittent supply may affect quality or quantity water supplied, and effectively render the quality of the service low.

3.2. Sources of water in the study sites

3.2.1. Multiple water sources

Households typically made use of an array primary, secondary and sometimes tertiary water sources. Four hundred and twenty households (64 %) reported using a secondary water source. Forty-six percent of those reporting using a secondary source were households *with* on-site supply. Only 36 % of households relied exclusively on one water source. This is consistent with findings from previous research, for example (Howard et al., 2002).

3.2.2. Main water source

Households in the three survey sites used an array of water sources. The main water sources are shown in Table 7. At-house water sources included house connections to piped systems, wells in the yard and private rainwater collection in Vietnam.

Communal taps were the most common shared water source in both Ghana and South Africa, while surface water was more common in Vietnam. The highest proportion of households using at-house water sources was in Vietnam, with just over three quarters of the sample having access to a supply at the house or yard.

It is perhaps worth noting that although communal taps were available in all the study communities in South Africa, some households reported their main supply as neighbours' private drilled wells, surface water (protecting springs) or municipal water tankers.

Table 7: Main water sources in Ghana, South Africa and Vietnam

		Ghana N (%)	South Africa N (%)	Vietnam N (%)
At-house water sources	Piped supply with HH tap	8 (3.1%)	43 (20.9%)	10 (5.1%)
	Piped supply with yard tap	57 (22.4%)	6 (2.9%)	87 (43.9%)
	Private well (mechanical pump)	4 (1.6%)	54 (26.2%)	40 (20.2%)
	Private well (manual lifting pump)	36 (14.1%)		11 (5.6%)
	Private rainwater collection	-		4 (2.0%)
	Total private sources	105 (41.2 %)	103 (50 %)	152 (76.8 %)
Shared water sources	Shared piped supply with tap	112 (43.9%)	79 (38.3%)	5 (2.5%)
	Shared well with manual pump	20 (7.8%)	-	-
	Shared well with manual lifting	18 (7.1%)	-	2 (1.0%)
	Shared supply surface water		4 (1.9)	38 (19.2%)
	Buying water from neighbours		11 (5.3%)	-
	Other – outside of home (municipal water tanker)		9 (4.4%)	-
	Total shared sources	150 (58.8 %)	103 (50 %)	45 (22.7 %)
	Total households	255 (100 %)	206 (100 %)	197 (99.5 %)

3.2.3. Reliability

Although the majority of main water sources used in the survey were those conventionally classified as ‘improved’, the reliability of the water supplies was low in Ghana and South Africa in particular. On average, water was unavailable for three days of the week in Ghana and South Africa, while in Vietnam it was typically unavailable for one day per week (Table 8). Reliability was reported by household members to be a particular issue for piped supplies.

On the days when it was available, water was supplied for most of the day in all three survey sites. However, breakdowns in the supply system reportedly took an average of a month to repair in South Africa, while in Vietnam repairs were within a day. In Ghana the average time for repairs was just over one week. Just over a quarter of households reported that their domestic water needs were not met all the time (Table 9).

Table 8: Summary statistics on water supply reliability

Variable	Country	N (%valid)	Mean (SD)	Median	Mode	Min	Max	Range
Number of days without water supply per week	South Africa	201 (97.6%)	2.5 (4.2)	1	0	0	30	30
	Ghana	222 (87.1%)	3.0 (3.8)	2	0	0	16	16
	Vietnam	197 (99.5%)	0.8 (2.1)	0	0	0	14	14
Hours of supply per day	South Africa	198 (96.1%)	18.7 (8.2)	24	24	0	24	24
	Ghana	199 (78.0%)	18.7 (8.3)	24	24	0	24	24
	Vietnam	142 (71.7%)	22.1 (5.2)	24	24	1	24	23
Time taken to repair breakdowns (days)	South Africa	110 (53.4%)	34.8 (47.2)	30	30	0	365	365
	Ghana	105 (41.2%)	8.5 (26.5)	3	0	0	210	210
	Vietnam	101 (51.0%)	1.2 (2.8)	0	0	0	24	24

South Africa n = 206; Ghana n = 255; Vietnam n = 198

Table 9: Adequacy of water for domestic needs

	Shared	Private	Total
No	64 (21.5%)	26 (7.2%)	90 (13.7%)
Less than half of the time	17 (5.7%)	10(2.8%)	27 (4.1%)
About half of the time	9 (3.0%)	10 (2.8%)	19 (2.9%)
More than half of the time	11 (3.7%)	27 (7.5%)	38 (5.8%)
Yes	196 (66.0%)	286 (79.7%)	482 (73.5%)

For those households where supply was inadequate a major reported reason was temporal variation in supply (Table 10). Households that had at-house water supplies cited seasonal availability of water, water pressure as well as temporal availability of water at the source amongst the reasons for having inadequate water quantities.

Table 10: Reasons why water supply is inadequate

	Shared	Private	Total
Storage problems	3 (3.2%)	2 (3.2%)	5 (3.2%)
Number of water collectors	6 (6.5%)	1 (1.6%)	7 (4.5%)
Number of water collection containers that can be used	3 (3.2%)	0 (0%)	3 (1.9%)
Temporal availability of water at source	23 (24.7%)*	16 (25.4%)*	39 (25.0%)*
Seasonal availability of water at source	8 (8.6%)	19 (30.2%)*	27 (17.3%)*
Power to extract water from source of water	2 (2.2%)	1 (1.6%)	3 (1.9%)
Reliability or predictability of source of water	2 (2.2%)	0 (0%)	2 (1.3%)
Price	16 (17.2%)	4 (6.3%)	20 (12.8%)
Water pressure	11 (11.8%)	16 (25.4%)*	27 (17.3%)*
Accessibility (location) to supply	19 (20.4%)*	4 (6.3%)	23 (14.7%)

3.3. Distance to source and water consumption

3.3.1. Summary findings from the systematic review of literature

The full text of the systematic review of literature will be made available in an open access journal article.

The Cairncross curve of travel time and water consumption (Figure 1) suggests that water consumption drops substantively when water sources are located at distances greater than 30 minutes (1 km) away. At distances between 5 and 30 minutes, per capita water consumption remains relatively constant, but dramatically rises as water becomes available within five minutes of the household.

A systematic review of studies was conducted in order to assess the evidence for this phenomenon and its implications for new recommended standards on distance to water sources. A search of peer reviewed journal articles was conducted in three academic databases, PubMed, Embase, and Global Health. The search was conducted in January 2013 and included articles published between January 1970 and January 2013[2]. No language restrictions were imposed however only articles published in English were examined for review. Location was restricted to developing countries through search terms.

Studies were excluded if they did not report data on water consumption and time or distance from the household to the main water source. Papers collecting both quantity and distance or time but not reporting them together were also excluded. Authors were contacted in cases where both water quantity per capita and distance (or time) to water source data were collected but not published in the results.

[2] Global Health contained articles from January 1972 and Embase contained articles from January 1973.

Data extraction from the studies included details regarding the time and setting of the study, the study design, statistical analysis used, and methods related to data collection. Particular attention was paid to the method used for measuring distance (or time) and the quantity of water used per day. Although some articles were unclear in their methods and analysis, there was no restriction based on study quality.

The search identified 5,961 potentially relevant articles from three databases of peer reviewed journal articles with 17 articles being included in the final review. An additional eight articles and books were identified based on a search of bibliographies of included papers. Further details will be published in a forthcoming paper reporting the findings of this review.

A review of the included studies resulted in the following key findings:

- There are very few studies investigating factors affecting water use in developing countries. Since 1968, only 25 studies have reported data on both water quantity and distance to the water source (or collection time). Of the 25, only 15 studies were specifically examining water consumption.
- Reported studies represent a mix of study designs, sampling schemes, data collection methods and approaches to statistical analysis. This complicates comparison of study results and derivation of overall conclusions regarding the relationship between the distance to water sources and household water use.
- Self-reported data on water use were used in seven studies and only five studies used direct measurement to obtain quantity data. Data on distance to the water source was directly measured in nine studies and in five studies the method was unclear.
- Results from included studies were mixed; eight studies reported no relationship between distance to the water source and water use and 12 presented data suggesting a decrease in water consumption with increasing distance. The differences in results could be due to differences in study design, data collection methods, assumptions, or geographical and cultural practices.
- The five studies comparing households having at-home supplies with those using off-plot sources show a substantially greater quantity of water used when water is available on-home.
- The identified papers show a pronounced geographical bias towards Sub-Saharan Africa (SSA). This may be due in part to the search being restricted to articles published in English. Three-quarters of the included studies were conducted in SSA, with the remainder conducted in Latin America and the Caribbean, North Africa, Southern Asia and South-eastern Asia. The Millennium Development Goal regions of Western Asia, Oceania, Caucasus and Central Asia, and Eastern Asia, were not represented in the literature.
- The majority of studies were performed in rural settings. Two papers contained study sites in both rural and urban communities and only one paper looked at water use patterns in peri-urban communities.

Current policy appears to be based on a handful of studies White et al. (1972), Feacham (1978) and Cairncross and Cliff (1987), performed over 30 years ago and summarised by Cairncross in 1987. The existing literature presents a mixed picture of water use patterns reflecting the complex dynamics governing water behaviour for those relying on off-plot water sources. In contrast, the included studies comparing households with at-home supplies and households using off-plot sources show a consistently greater water use.

At the moment, at-home water supplies are not available for all households with rural households less likely than urban households to enjoy this type of supply. More rigorous studies would aid in determining what indicators are the most indicative of water use by households across all regions, in both rural and urban settings.

3.3.2. Summary findings from the fieldwork

Water quantity by source type

To examine the relationship between median water use and water source type, a quantile regression model was used. Quantile regression was used due to the presence of some extreme water use data points (indicated in **Appendix D**, Figure D.1). The method of least squares is used in some regression techniques to model the relationship between a covariate and the conditional mean of the outcome variable. Whereas the mean can be obscured due to outliers, the median is less influenced by extreme values. Quantile regression describes the relationship between a covariate and the conditional quantiles (median or other quantiles) of the outcome variable (Chen, 2005).

The quantile regression model was adjusted for country of study, crowding, highest level of education within the household, the number of types of assets owned, and water source type. Crowding was defined as the number of people in the household divided by the number of reported rooms within the home. Assets were defined as radios, televisions, mobile telephones, refrigerators, washing machines, cars, bicycles, motorbikes, and stoves. Crowding and number of assets were used to minimize confounding due to wealth and socio-economic status. Level of education has been shown to be correlated with water use and was therefore controlled for in the model (Sandiford et al. (1990)).

Figure 3 shows the median water use (lpcd) for households using different sources with bars indicating the 95% confidence intervals. Table 11 shows the results from the quantile regression model assessing the relationship between water quantity and water source type using communal standpipes as the basis for comparison between sources. Both Figure 2 and Table 11 show that there are significant differences in water use by source type ($p<0.0001$). The results from the quantile regression show the change in water use between sources, while Figure 2 shows the actual median water use for each source. The aggregated data was used for this analysis since disaggregating by country would lead to small samples sizes for some source types.

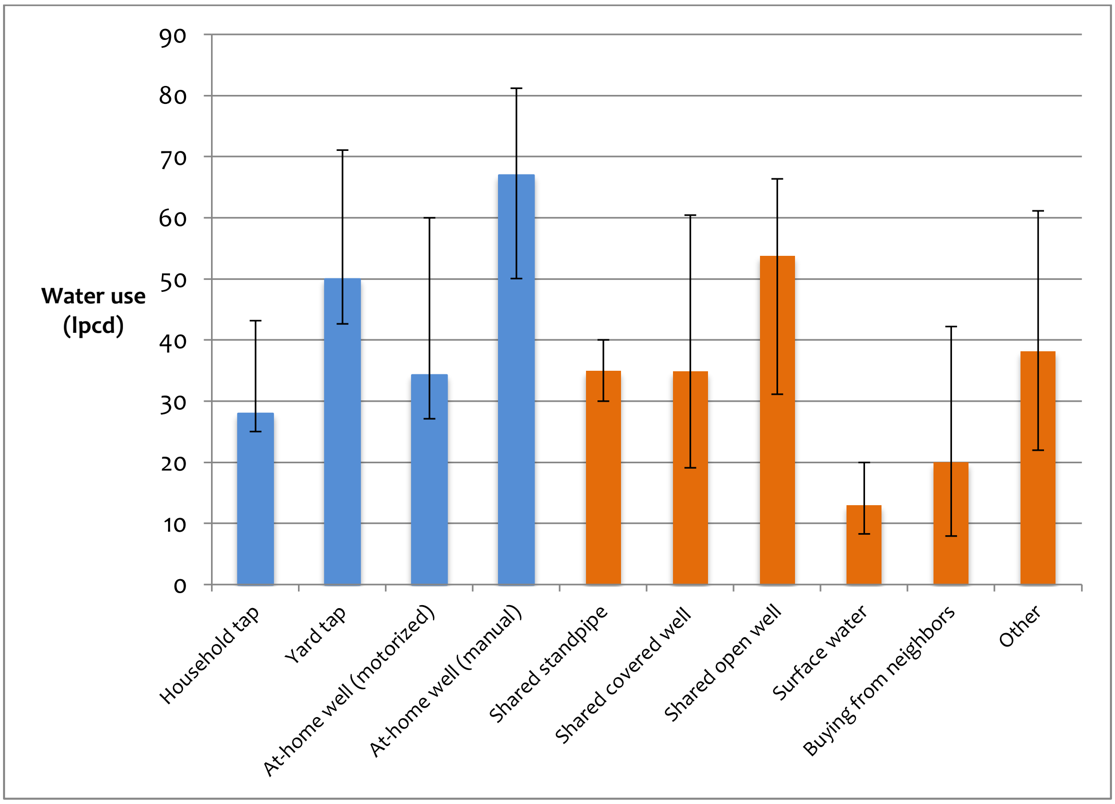

Figure 3: Median water use (lpcd) by source type (bars indicate 95% CI)

Note: At home sources are shown in blue and off-plot sources in orange. Rainwater collection is not shown due to the small sample size and wide confidence intervals

Table 11: Results from quantile regression of water use (lpcd) and location of water source (data from all three countries)

Water source	n	Extra water use	L95%CI	U95%CI
Shared standpipe	191	0		
Shared covered well with manual pump[1]	19	-0.6	-17.5	16.3
Shared open well with manual lifting	19	15.7	-1.6	33.0
Surface water	40	-19.3	-35.5	-3.1
Buy from neighbours	11	-11.1	-23.3	1.2
Other[2]	8	10.9	-14.1	35.9
Tap in house	37	-7.5	-20.9	5.8
Tap in yard	99	8.8	-1.8	19.3
At-house mechanical lift	52	-5.0	-18.0	8.0
At-house manual lift well	30	29.8	15.4	44.2
Rainwater collection	3	64.4	28.5	100.3

1- *Most often boreholes with handpumps*
2- *'other' most often tanker trucks*
Extra water use' refers to an increase or decrease in the median water quantity (lcpd) rather than the mean water quantity. ($F(10, 493) = 9.91$, $p<0.0001$).

The median per capita daily water consumption for households using shared standpipes was 35 lpcd. Households that identified shared manual wells as their primary source used 15.7 ± 17.3 lcpd more than households using public standpipes. Surface water users use considerably less water (19.3 ± 16.2 lpcd) than households using public standpipes. Households relying on surface water as their primary source had the lowest median water use of 13.0 ± 5.9 lcpd. Within the set of households using on-plot supplies, those with a piped supply used least water.

The results from Table 11 should be viewed in light of the sample sizes for each water source. While there were a substantial number of observations for public taps (n=191) and yard taps (n=99), some sources (shared pump well, shared manual well, rainwater collection, buying from neighbours, and other) had sample sizes less than 20 households, therefore conclusions regarding these sources cannot be made with statistical confidence.

At-home and off-plot supplies

We used a similar approach and quantile regression to examine the relationship between quantity of water used (lpcd) and the location of water sources.

The regression was done on the aggregated data from all three countries, and separately to examine possible different relationships occurring at the country level. Table 12 shows the results from the regression model comparing the difference in median water use using off-plot sources as the comparison.

In Ghana households with at-home supplies use 30.4 (16.1-44.8 95% CI) more water than households using off-plot sources, which was statistically significant (p<0.0001). The model for Vietnam showed the same relationship with at-house supplied households using 29.0 (-8.7-66.6) more water than off-plot households, however this was not statistically significant (p=0.130). Even after adjusting for other variables, South Africa still shows a different trend from Ghana and Vietnam with off-plot supplied households using more water than households with at-home supplies.

Table 12: Results from quantile regression of water use (lpcd) and location of water source as at-home or off-plot..

Country	Location of water source	Extra water use[1] (lpcd)	L95%CI	U95%CI	p
	Off-plot	0	---	---	---
All	At-home	10.9	2.9	18.8	0.007
South Africa	At-home	-13.4	-23.6	-3.2	0.01
Ghana	At-home	30.4	16.1	44.8	<0.0001
Vietnam	At-home	29.0	-8.7	66.6	0.130

[1]- *'extra water use' refers to an increase or decrease in the median water use (lpcd) rather than the mean water use*

Households fetching water off-plot

According to Cairncross (1987), the expected relationship between water quantity used and round-trip collection time is a steep decrease when the trip takes over five minutes; water quantity used remains constant between five and 30 minutes and declines again when the trip exceeds 30 minutes (See Figure 1). Round -trip collection times reportedly correspond to a distance of 1 kilometre from the home to the source (ibid.) although in reality walking speeds vary greatly by individual and terrain and queue times may also vary, all of which may affect travel time (White et al. (1972)).

Figure 4 shows the scatterplot of water quantity and measured round-trip time (min) to the primary water source for households using off-plot water sources in South Africa, Ghana, and Vietnam. The inverse relationship between water quantity used and round-trip travel time varies between countries. In comparison to Ghana and Vietnam, South Africa has a more uniform distribution of water quantity used for households between zero and 35 minutes from the source. In Ghana all households had a round-trip collection time less than 25 minutes, while in Vietnam households travelled less than 20 minutes round -trip.

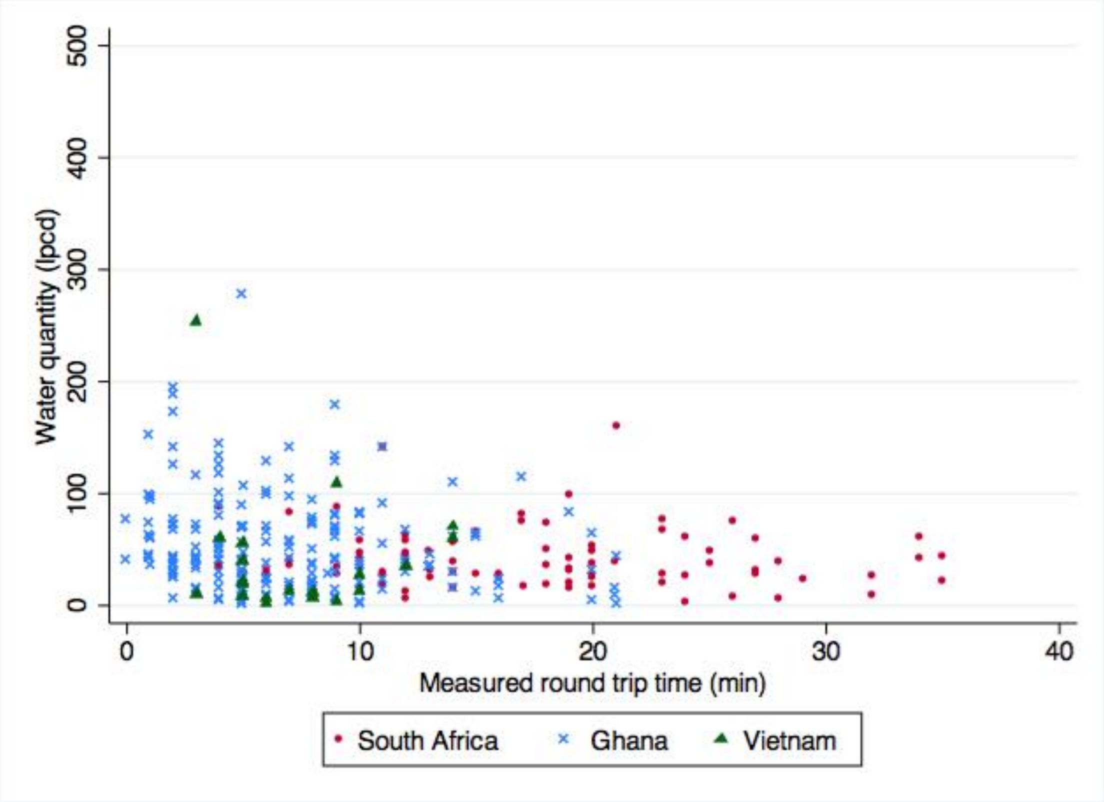

Figure 4: Scatterplot of water quantity (lpcd) and measured round-trip travel time to the primary water source for households using off-plot sources in all three countries with extreme values excluded.

Note : Refer to Appendix D for scatterplot with all values).

A quantile regression model was used to assess if time or distance had a significant relationship with water quantity for households using off-plot water sources. Self-reported round-trip travel time, measured round-trip travel time, and measured round-trip distance were used in regression analyses to see if one provided a more significant relationship with water quantity.

The results from the regression model for self-reported round-trip time for each country are shown in Table 13. Table 14 shows the results from the quantile regression model for measured round-trip time for each country, and Table 15 shows the results from the measured round-trip distance and water quantity.

Table 13: Results from quantile regression of water use (lpcd) and self-reported round-trip time.

Country	n	Extra water use[1]	L95%CI	U95%CI	p
South Africa	79	0.1	-0.1	0.4	0.368
Ghana	114	0.1	-0.5	0.8	0.710
Vietnam	40	-0.1	-0.6	0.3	0.637

[1]- *'extra water use' meaning for every increase in 10 minutes of self-reported round-trip time there was an increase or decrease in median water use by X lpcd.*

Table 14: Results from quantile regression of water use (lpcd) and measured round-trip time to source.

Country	N	Extra water use[1]	L95%CI	U95%CI	p
South Africa	86	0.6	-6.1	7.3	0.865
Ghana	132	-14.4	-32.8	4.1	0.126
Vietnam	17	-2.1	-36.5	32.4	0.897

[1]- *'extra water use' meaning for every increase in 10 minutes of measured round-trip time there was an increase or decrease in median water use by X lpcd.*

Table 15: Results from quantile regression of water use (lpcd) and measured round-trip distance to source.

Country[1]	n	Extra water use[2]	L95%CI	U95%CI	p
South Africa	86	0.2	-1.2	1.6	0.765
Ghana	139	-0.1	-5.2	4.9	0.955

[1] –No measured distance data was available for Vietnam

[2]- 'extra water use' meaning for every increase in 100 meters of measured round-trip distance there was an increase or decrease in median water use by X lpcd.

The results from the regression model for each country show no statistically significant relationship between self-reported round-trip time or measured round-trip time and water quantity. There was no statistically significant relationship for measured round-trip distance and water quantity for data from South Africa and Ghana. The results from the three sites were consistent in regards to no statistical relationship for self-reported and measured round-trip time. While there was no measured distance data from Vietnam, the results for South Africa and Ghana both showed no relationship for round-trip distance and water quantity.

Location of water using activities

Drinking water accounts for only a fraction of water used by households. Other uses can have large impacts on the quantities of water used, both for domestic and productive purposes. Domestic uses such as laundry or bathing require more water than is used for drinking and food preparation. Many water quantity papers only record the amount of water carried home by households in their calculations of water quantity. The location where households perform certain tasks can impact the calculated water use per person. As part of the household survey, respondents were asked to identify where they performed various domestic and productive activities requiring water (at home, at the source, elsewhere, or in multiple locations). The disaggregated results for households using off-plot water supplies in South Africa, Ghana, and Vietnam are shown in Table 16. Less than 10% of households using off-plot water supplies in any of the countries performed domestic water-using activities (bathing, laundry and cleaning dishes) on plot.

Table 16: Locations of domestic water-using activities by households using off-plot supplies (South Africa, SA n = 206; Ghana, GH = 255; Vietnam, V = 198).

Activity	Country	n (% HH)	Location of water-using activity			
			At Home	At Source	Else where	Multiple locations
Bathing	SA	103 (50.0%)	103 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	GH	148 (58.0%)	147 (99.3%)	1 (0.7%)	0 (0.0%)	0 (0.0%)
	V	45 (22.7%)	6 (13.3%)	39 (86.7%)	0 (0.0%)	0 (0.0%)
Laundry	SA	103 (50.0%)	72 (69.9%)	15 (14.6%)	10 (9.7%)	6 (5.8%)
	GH	148 (58.0%)	145 (98.0%)	3 (2.0%)	0 (0.0%)	0 (0.0%)
	V	45 (22.7%)	2 (4.4%)	43 (95.6%)	0 (0.0%)	0 (0.0%)
Cleaning dishes	SA	103 (50.0%)	103 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	GH	148 (58.0%)	147 (99.3%)	1 (0.7%)	0 (0.0%)	0 (0.0%)
	V	45 (22.7%)	34 (73.9%)	12 (26.7%)	0 (0.0%)	0 (0.0%)

Households in Ghana and South Africa often bathed and washed clothes at home rather than at the source. In contrast, a larger percentage of households (85% bathing, 94% laundry) using off-plot supplies in Vietnam reported performing these tasks at the source.

Very few households reported using water for productive uses such as farming and commercial services. More households in Vietnam (n=16) specified using water for agricultural purposes than households in Ghana (n=6) or South Africa (n=2). Ghana had the largest number of households reporting commercial activities utilizing water (n=18), which include but are not limited to food preparation, laundry for others, and washing vehicles.

In terms of productive uses, more households in Vietnam reported using water for farming (n=73) than households in South Africa (n=10) and Ghana (n=13). Table 17 shows the reported number of households from each country using water productively and the location of water use. Ghana had the largest number of households reporting commercial activities utilizing water (n=36), which include but are not limited to food preparation, laundry for others, and washing vehicles.

Table 17: Locations of productive water-using activities by households using off-plot supplies (South Africa, SA n = 206; Ghana, GH = 255; Vietnam, V = 198).

Activity	Country	n (% HH)	Location of water-using activity			
			At Home	At Source	Else where	Multiple locations
Farming[1]	SA	10 (4.9%)	10 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	GH	13 (5.1%)	6 (50.0%)	2 (16.7%)	4 (33.3%)	0 (0.0%)
	V	73 (36.9%)	0 (0.0%)	62 (84.9%)	11 (15.03%)	0 (0.0%)
Commercial services[2]	SA	2 (1.0%)	2 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	GH	36 (14.1%)	20 (66.7%)	6 (16.7%)	7 (19.4%)	3 (8.3%)
	V	6 (3.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

1- Includes agriculture, aquaculture, raising livestock
2- Includes preparing food, laundry for others, washing vehicles

Selection of additional sources

Issues of seasonality, source reliability, cost, and convenience can lead to households choosing to use alternative sources in addition to or in place of their primary sources. Households may also chose to use different sources based on the purpose for which they are using water. For example, some households may use an improved source farther away for drinking water, but use an unimproved source next to their house for bathing. In order to better assess the extent and variation of multiple source use, households were asked to specify whether they used their primary water source or an additional water source for different activities. The results from the three countries are presented in Table 18.

Table 18: Reported use of main and additional sources for various water-using activities (South Africa, SA n = 206; Ghana, GH = 255; Vietnam, V = 198).

Activity	Country	n (% HH)	Main source	Alternative source	Main and alternative
Drinking	SA	206 (100%)	58 (28.2%)	2 (1.0%)	146 (70.9%)
	GH	252 (98.8%)	81 (32.1%)	30 (11.9%)	141 (56.0%)
	V	197 (99.5%)	162 (82.2%)	16 (8.1%)	19 (10.6%)
Preparing food	SA	205 (99.5%)	59 (28.8%)	0 (0.0%)	146 (71.2%)
	GH	252 (98.8%)	219 (86.9%)	3 (1.2%)	30 (11.9%)
	V	197 (99.5%)	168 (85.3%)	12 (6.1%)	17 (8.6%)
Bathing	SA	206 (100%)	59 (28.6%)	0 (0.0%)	147 (71.4%)
	GH	252 (98.8%)	221 (87.7%)	0 (0.0%)	31 (12.3%)
	V	197 (99.2%)	163 (82.7%)	17 (8.6%)	17 (8.6%)
Laundry	SA	205 (99.5%)	57 (27.8%)	3 (1.5%)	145 (70.7%)
	GH	252 (98.8 %)	225 (89.3%)	2 (0.8%)	25 (9.9%)
	V	196 (99.0%)	150 (76.5%)	21 (10.7%)	25 (12.8%)
Cleaning house	SA	206 (100%)	59 (28.6%)	0 (0.0%)	147 (71.4%)
	GH	251 (98.4%)	225 (89.6%)	1 (0.4%)	25 (10.0%)
	V	102 (51.5%)	94 (92.2%)	2 (2.0%)	6 (5.9%)
Gardening	SA	44 (21.4%)	29 (65.9%)	0 (0.0%)	15 (34.1%)
	GH	46 (18.0%)	24 (52.2%)	12 (26.1%)	10 (21.7%)
	V	135 (68.2%)	96(71.1%)	22 (16.3%)	17 (12.6%)

A high percentage of households in South Africa (70.9%) and Ghana (56.0%) reported using main and an additional source (multiple sources) for drinking. In Ghana, the field researchers observed the frequent use of sachet water, 250 mL of drinking water sealed in plastic. A large portion of study households in Ghana (61.2%) reported using bottled or sachet water as an additional source, which contrasts sharply with the other peri-urban communities from South Africa which did not report any use of bottled or sachet water (Table 19).

Table 19: Number of households reporting use of bottled water or sachet water.

	South Africa	Ghana	Vietnam
Bottled/sachet water	0 (0.0%)	156 (61.2%)	4 (2.0%)
Total	206	255	198

For activities other than drinking, households in South Africa reported using their main and additional sources. Interestingly, the reverse is seen for households in Ghana, where most households used their main water source exclusively for all activities other than drinking. Households in Vietnam predominately used only their main source for all domestic activities.

Table 20 shows the reported number of additional sources used by sampled households. Bottled water and sachet water were separated (Table 19) since these alternative water sources are a unique category. More households in South Africa (72.8%) and Vietnam (59.0%) use additional sources compared to Ghanaian households (26.2%). Table 21 breaks down the reported additional sources by type. The results shown in Table 22 account for all reported additional sources used by households except for sachet water and bottled water. Public standpipes were the most reported additional source used in Ghana (30.4%). In contrast, surface water accounts for 56% and 48% in South Africa and Vietnam, respectively.

Table 20: Number of additional sources used by households in each country.

Number of alternative sources used	South Africa HH (%)	Ghana HH (%)	Vietnam HH (%)
0	56 (27.2%)	76 (73.8%)	107 (54.9%)
1	149 (72.3%)	2 (2.0%)	75 (38.5%)
2	1 (0.5%)	21 (20.4%)	10 (5.1%)
3	0 (0.0%)	4 (3.9%)	3 (1.5%)
Total HH	206	103	195

Table 21: Types of additional sources reportedly used by households reporting at least one alternative source.

Alternative water source type	South Africa	Ghana	Vietnam
Household tap	0 (0.0%)	0 (0.0%)	1 (0.9%)
Yard tap	0 (0.0%)	4 (7.1%)	5 (4.8%)
Private well (motorized pump)	0 (0.0%)	0 (0.0%)	3 (2.8%)
Private well (manual lift)	0 (0.0%)	4 (7.1%)	1 (1.0%)
Rainwater collection	2 (1.3%)	- [1]	29 (26.9%)
Public standpipe	14 (9.3%)	17 (30.4%)	9 (8.3%)
Shared covered well (manual lift)	0 (0.0%)	6 (10.7%)	3 (2.8%)
Shared open well (manual lift)	0 (0.0%)	16 (28.6%)	1 (0.0%)
Surface water	85 (56.3%)	9 (16.1%)	52 (48.2%)
Buying from neighbors	36 (23.8%)	0 (0.0%)	0 (0.0%)
Other	14 (9.3%)	0 (0.0%)	0 (0.0%)
Total alternative sources reported	151	56	104

1- *"rainwater collection" was translated as "rain"therefore rainwater collection data was excluded for Ghana.*

Discussion

The field data from all three countries reveal an important relationship between whether water supplies are located on- or off-plot and water quantity. The aggregated data from all three countries showed households with at-home water sources used a significant ($p=0.007$) more amount of water (10.9 ± 8.0 lpcd) compared to those needing to fetch water outside their house.

Looking at the sample of selected communities and households in individual countries, Ghana and Vietnam showed a higher water use in households with at-home water supplies. There appears to be a different trend in South Africa, where households using off-plot supplies use more water than households with on-plot supplies. This is most likely due to an underreporting by households using at-home water supplies. The predominate at-home water supplies in South Africa were household taps and private wells with a motorized pump. Municipal water bills were not available for households, which meant the respondents estimated total daily water use. All of the on-plot wells used motorized pumps that pumped water into a 2,500 litre or larger storage tank from which households withdrew water from a tap connected to the tank. One field researcher observed respondents storing a 2-litre container of water in a refrigerator for drinking purposes and for other uses water was directly drawn from the tank tap. This could have resulted in an under estimation since households with in-house taps and motorized wells are not necessarily filling buckets and making specific water fetching trips, which would be easier to recall.

Counter-intuitively, respondents using household taps had a lower median water use (28.0 ± 9.1 lpcd) compared to households with yard taps (50.0 ± 14.3 lpcd). This result could be due to the effect of the data from all three countries being pooled together in the analysis. A systematic under-reporting by households having a tap within the home compared to those having to go out to the yard to collect water could also be the reason for this result. Another possibility for the lower water use by household taps could be the sharing of water supplies with neighbours. Households would be more prone to collect water from their neighbour's yard tap than an interior household tap. The location of where households were performing tasks such as washing clothes or cleaning dishes, or gardening could be another reason for the discrepancy between household and yard taps. Households could use yard taps more for these activities, which use more water than activities such as drinking and cooking.

For households using off-plot supplies, shared open wells reported the highest median quantity (53.8 ± 17.6 lpcd), compared to other off-plot sources. This could be due to tariff structures or varying queue times at the different public sources. If queue times are longer at certain public sources, water carriers could chose to use other sources and make more frequent trips. It could also be due to the fact that the availability of water in wells is more consistent and reliable than the availability of water in other supplies, particularly in taps. Households reported 'temporal availability of water' as one of the main reasons for dissatisfaction with their main water supplies, suggesting that an sporadic or unpredictable supply created problems in terms of water collection. The higher rate of consumption in wells when compared to taps could also be seen amongst households with at-home supplies, suggesting that this aspect of reliability may hold irrespective of the location of the source.

The results from the quantile regression models for self-reported and measured round-trip travel time and measured round-trip distance demonstrate no statistical significant relationship with water quantity, but there also appears to be no evidence to substantiate a general plateau effect where water use remains constant between five and 30 minute round-trip collection times. There was no indication that any of the three independent variables (self-reported travel time, measured travel time, and measured distance) provided a better indicator for water quantity used. Neither round-trip time or round-trip distance provided an accurate predictor for the amount of water households accessed when it was located off-plot. Comparing the results from self-reported travel time and measured travel time did not reveal whether either method provided a better estimate of water quantity used by households.

The data on households collecting water off-plot from all three countries reveal no significant relationship between distance and water quantity. The thresholds at five and 30 min noted by Cairncross (1987) are not clearly observed in the sample as shown in Figure 4. Few households within the sample travelled further than 1 km to their water source; of those who did, the vast majority were in South Africa. This would explain why a decrease in water use was not seen in the data since households were not walking far enough to see the effect. The lack of a relationship between distance and water quantity is consistent with other studies (Verweij (1991) and West (1989)). The part of the curve depicting a substantially higher quantity of water used when water is located on premise, however, is supported by the pooled field data from all three countries.

Water use patterns were different between the study sites with the majority of bathing and laundry being done at home in Ghana and South Africa while these activities more frequently occurred at the source for Vietnamese households. All communities in South Africa and Ghana were peri-urban, while all the study sites in Vietnam were rural. The difference in location could be due to the variation in settings or even due to the source type available. In South Africa and Ghana, the principal off-plot water source was public standpipes (77% and 75% respectively), while in Vietnam the principal off-plot source was surface water (84%). Respondents might have felt more comfortable bathing at a river compared to bathing at a public standpipe. Cultural differences could also account for the different behaviour between the three sites with two being in Africa and the other being in South-Eastern Asia.

The variation in water behaviour between the three countries has been noted in other studies. Noda (1997) conducted a schistosomiasis intervention study in rural Kenya and reported people bathing and cleaning their clothes at the river. Similarly, Gazzinelli (1998) observed households washing their clothes and utensils in the river during a water use study in rural Brazil. Similar to the results from Vietnam, Polack (2006) noted that bathing and laundry occurred at the home rather than at the source in their study in rural Tanzania. In their introduction, Mertens (1990) reported that throughout rural Sri Lanka, all water used for domestic purposes was carried back to the home. Although the communities within our study were not nationally representative, the results demonstrate that the location of water-using activities can vary between geographic contexts. This highlights the importance of validating the implicit assumptions regarding where water is used in data collection methods when studying water use.

Although more households in Vietnam reported using water for farming purposes, this could be due to the different settings of the study communities. The study sites in South Africa and Ghana were peri-urban, whereas the study sites in Vietnam were all rural communities. This could also account for the higher portion of households in Vietnam who reported using water for gardening. More households with on-plot water supplies (57.1%) reported using water for gardening than households using off-plot supplies (11.6%). This could mean there are important nutritional benefits for households with on-plot water supplies in rural areas.

It is not clear if the estimated household water quantity included water used for productive uses or not. Water quantity data from households with a water meter would have captured water used for commercial purposes, however if households chose to use a different source other than their house tap or yard tap, the quantity might not have been reflected in the per capita water use. Households were not specifically prompted to consider water used for commercial purposes when asked about water collection patterns. The section in the survey inquiring about water source type used and the location of activities occurred after respondents were asked about their water collection habits.

An interesting finding was the high percentage of households in Ghana using sachet water. In comparison, the peri-urban study communities in South Africa did not report using bottled or sachet water, which could be due to cost, user preference or unavailability of these sources. While sachet water was not indicated as the primary drinking source, it could account for a substantial amount of drinking water ingested outside the home. Since sachet water is readily available in certain settings, it could be a significant way to provide quality drinking water and therefore reduce the risk of water-borne diseases.

There were also differences in the use of multiple sources between the three countries. More households in South Africa and Vietnam used at least one additional source compared to Ghanaian households who primarily used one water source (after separating out sachet water). The specific reasons for why households chose to use an additional source were not addressed in this study, but the findings show that in order to accurately determine total water quantity, multiple sources should be considered in the data collection methods. Since the questionnaire was administered in the wet season, it is unlikely due to seasonal effects where the main source has run dry. In a multi-country study in East Africa, Thompson (2011) reported issues in water system service to be a reason for households using other sources. Other explanations for using multiple water sources could be due to cultural habits (location of bathing and laundry) or simply due to user preference. Mertens (1990) reported taste being an important element in water source selection for drinking water

Conclusions

The results from the field studies in Ghana, and Vietnam show a statistically significantly higher water use by households with at-home supplies compared to those who use off-plot supplies. Although this trend was not demonstrated in South Africa it was most likely due to recall bias from under-reporting water use for at-home water supplies.

Quantile regression revealed no relationship between distance to the water source (or collection time) and water quantity used for households relying on off-plot water supplies. Factors affecting water quantity for households fetching water are nuanced and can range from weather patterns to issues of supply or personal preference. In this study, the volume of water collected per trip was verified through the measured mass of the filled water container, however the calculation of litres per capita per day (for households relying on off-plot sources) relied on self-reported data such as number of trips per day and the number of days per week that households collected water. The observation period was also limited to one water carrier on one water collection trip. Thus, some uncertainty is introduced by the unknown accuracy of these user self-reports.

While the impact of distance on water quantity appears complex, the higher water use for those households having at-home water supplies has been demonstrated in this study and others. If international policies aim to substantially increase the amount of water used by households, then simply bringing off-plot water supplies closer to users' homes may not provide sufficient improvement for households to raise their water quantities. Rather than aiming for improved water supplies to be within 30 minutes of the household, there should be a focus on at-home water sources, which has been shown to increase water quantity.

Our results also shows higher water use by households using wells when compared to those using taps both for households whose water source is at the house or yard and those whose water source is outside the home. These results are less robust due to the relatively small sample size for households reliant on wells in some of the study sites but they merit consideration. When considered in tandem with the reported high levels of dissatisfaction with temporal variations in supply this finding suggests that reliability of all sources, but piped supplies in particular, may be at least as important as their distance from the household.

While the communities within this study are not nationally representative, there were interesting differences in water use patterns between the three countries. Most water behaviour studies only collect data about water carried back to the household, without considering water used at the source. In Ghana and South Africa, most activities involving water use occur at the home, but this is not the case in the households studied in Vietnam. Data collection methods for household water use should take into account cultural behaviours and seek to account for all water used by the household, whether at home or at the source. Further research on water quantity and water use patterns employing more detailed observation methods could aid in developing more effective international policies to increase water access for households.

3.4. Health benefits of at-house water supplies (water-related diseases)

3.4.1. Summary findings from a systematic review of the literature

We carried out three reviews of the literature relating health outcomes to water sources. The first was a systematically organised review of the literature on the health benefits of at-house water supplies. A write up of this review will be published separately The paragraph below summarises the findings from the review.

Research evidence indicates that decreased household distance to water source reduces risk and prevalence of diarrhoea, trachoma, and other water-washed diseases.

However, these findings have not been compiled to investigate whether households with at-house water supplies experience better health than households without water supplies on the premises.

A systematic literature review was conducted on at-house water sources and their impacts on diarrhoea, trachoma, child growth, and other water-washed infections to further examine the relationship between distance to water source and health and assess whether there is evidence within literature that use of at-house water supplies generates health gains for households.

The literature search was conducted in three computerized databases of peer-reviewed journals: Embase, Global Health, and PubMed. The search included terms to describe water sources within household premises and targeted common water-washed agents and diseases. Studies conducting secondary research were excluded from the literature review; therefore, child mortality was not included in the search terms due to mortality study reliance on census data or hospital records. Peer-reviewed studies written in English from 1970 to 2013 were included in the screening.

The titles of all search results were screened, and potentially relevant studies were marked for abstract review. Abstracts were reviewed for relevance and were included in the full-text review, where studies were stringently screened by exclusion and rigor criteria. The bibliographies of accepted studies were also screened for relevant studies.

The initial electronic search retrieved 2,298 citations, and 44 studies were selected for the final analysis. Studies demonstrated varied results on the impact of at-house water sources on household diarrhoea and growth outcomes, while within a smaller number of studies, reductions in trachoma, helminth infections, and Hepatitis A were significantly correlated with the use of at-house water sources. The heterogeneous findings regarding the effects of at-house water supplies on diarrhoea and growth outcomes may be explained by variability in study designs and multiple aetiologies, in particular the fact that the incidence of a range of pathogens varies in different contexts and that different pathogens are influenced by hygiene and water quality to a different extent.

Few studies examining the health impacts of at-house water sources investigated distance to water source, and the lack of evidence for this link reveals an important gap in current literature. More studies that jointly examine the impacts of at-house water supplies and distance to water source on water-washed diseases are needed to better understand the synergy between these two factors and their contributions to household health.

3.4.2. Hygiene behaviours and at-house water supplies

The second review took a rapid look at the literature which links at-house water supply to hygiene behaviours. Improved hygiene is an integral element of the hypothesis which links improved water supply with improved health so we deemed it useful to examine the literature on this topic.

Hygiene and health

Personal and domestic hygiene activities are critical determinants of household health. In the classic F-diagram developed by Wagner and Lanoix, faecal-oral diseases stem from the transmission of human excreta to food via fingers, flies, fluids, and fields (Wagner and Lanoix (1958)). Safe hygiene practices can block all of these transmission pathways. Safe stool disposal reduces excreta in the environment and can reduce fly transmission of faecal matter to food and utensils. Latrine use limits human exposure to excreta and has been shown to reduce household diarrhoea (Baltazar et al. (1988), Daniels et al. (1990)). Washing hands after defecation prevents cross-contamination of domestic water supplies, dishes, and food, lowering exposure for other household members (Pinfold (1990)). Handwashing blocks several transmission routes of diarrhoeal pathogens and has been shown to significantly reduce diarrhoeal morbidity (Esrey et al. (1991), Cairncross et al. (2010)).

Hygiene affects not only household diarrhoea outcomes, but also has been shown to positively impact outcomes of water-washed diseases. Studies have demonstrated that clean faces are significantly associated with reduced trachoma prevalence ((Taylor et al., 1989), West et al. (1991), Hsieh et al. (2000), Golovaty et al. (2009)) and that frequent washing is associated with lower prevalence of trachoma (Cumberland et al. (2005)) and skin infections (Verweij et al. (1991)). Handwashing has been shown to significantly reduce prevalence of respiratory infections (Ryan et al. (2001), Rabie and Curtis (2006), Aiello et al. (2008)). Evidence suggests that hand and face washing can generate significant reductions of faecal-oral and water-washed diseases, exemplifying the Mills-Reicke phenomenon of producing not additive, but multiplicative health gains.

Hygiene and water access

Many household hygiene activities, such as washing, bathing, and cleaning, are dependent on water availability in the household. Several studies have demonstrated that households in close proximity to their water sources have greater domestic water supplies than households using distant water sources (Frankel and Shouvanavirakul (1973), Tonglet et al. (1992), Gazzinelli (1998), Aiga and Umenai (2002)). White et al (1972) suggested in the seminal Drawers of Water study that households with improved water access can allocate greater quantities of water for hygiene activities. This notion has been supported by more recent studies demonstrating that households with at-house water supplies use greater quantities of water for hygiene activities such as bathing and handwashing (Thomson (2001), Schémann et al. (2002)). .

Researchers have investigated how water allocation for hygiene affects household hygiene behaviour. Availability of soap and handwashing water near latrines has been shown to significantly increase frequency of handwashing (Lopez-Quintero et al. (2009), Mariwah et al. (2012)), and one study reported that mothers' dissatisfaction with the quantity of water available for hygiene was significantly associated with faecal contamination of both mothers' and children's hands (Pickering et al., 2010).

The hygiene impacts of water access and domestic water supply are corroborated by studies examining the relationship between household distance to water source and hygiene. In a study conducted in Mozambique, households living less than one kilometre from their water source used 70% of their domestic water supply to bathe, wash clothes, and bathe children on a daily basis, whereas households four kilometres from their water source used less than half of their water supply for hygiene-related activities and only rarely bathed their children (Cairncross and Cliff, 1987). Households in rural Swaziland used greater quantities of water for hygiene and bathed and washed hands more frequently after the implementation of water projects that decreased distances to water sources (Peter (2010)).

Additional evidence suggests that households with at-house water supplies experience hygiene gains. A study in Burkina Faso reported that households with domestic water connections were more likely to dispose excreta safely than households using water sources off the premises or outside of the compound (Curtis et al. (1995). Good handwashing practices have been shown to be more prevalent among Indian adolescents with at-house water supplies than among their peers using other water sources (Dobe et al., 2013). Ownership of a private well was a significant predictor of handwashing after defecation among mothers in a study conducted in the Philippines (Sakisaka et al. (2002)). Households in Kenya with at-house water supplies were shown to be significantly more likely to wash hands with soap and wash hands after contact with faecal matter than households using wells in the compound, boreholes and tubewells, water from vendors, or surface waters (Schmidt and Cairncross (2009)).

While these findings indicate a significant link between household water access and hygiene behaviour, they are solely associations and do not provide evidence for a causal relationship. Factors such as socio-economic status and maternal education may have confounding effects in study results. However, the consistency within literature of reported positive hygiene outcomes for households with improved water access and the lack of evidence demonstrating equivocal or negative hygiene outcomes suggest that increased proximity to water source not only can affect household allocation of domestic water supply for hygiene, but may also encourage safe hygiene behaviour.

Summary

Hygiene is a nexus for water and sanitation in the transmission of faecal-oral diseases and also has a critical role in water-washed diseases. Safe hygiene behaviour can unlock a multitude of health gains, and improved water access may facilitate hygiene improvements through greater domestic water supply and water allocation for hygiene activities. Evidence from research literature indicates that safe hygiene practices increase with household proximity to water source, presenting significant benefits and opportunities for the health and well-being of households in developing countries.

3.4.3. Impact of at-house supplies on skin and eye disease and diarrhoea

Detailed data sets on health outcomes were assembled from our field studies. These merit further detailed analysis but the preliminary findings are shown below. Analyses for health outcomes were done using a Generalised Estimating Equation (GEE) adjusted for age and sex and accounting for clustering at the household and country level. GEE is useful for predicting generalised effects across the population and is particularly useful for cohort studies with multiple sites. Where the outcome variable was binary we used negative binomial regression with a log link. Where the outcome variable was scalar we used linear regression models (Table 22).

Table 22: Water predictors for skin disease, eye disease and diarrhoea in previous two weeks adjusted for age and sex

Health outcomes	Predictors	N	RR	L95%CI	U95%CI	P
Skin disease	At home water source	2880	1.129	0.770	1.656	0.534
	Any water fetched from out of home	2882	1.027	0.696	1.515	0.895
	Estimated time to source/min	2215	0.977	0.941	1.015	0.231
	Estimated water used/p/d	2431	0.999	0.995	1.003	0.602
	Measured round trip distance/m	1476	0.998	0.997	0.999	0.003
	Measured round trip time/min	1532	0.949	0.904	0.996	0.032
Eye disease	At home water source	2879	1.076	0.820	1.411	0.597
	Any water fetched from out of home	2881	1.073	1.361	2.250	0.647
	Estimated time to source/min	2215	0.983	0.960	1.007	0.168
	Estimated water used/p/d	2430	0.999	0.996	1.002	0.453
	Measured round trip distance/m	1476	1.000	0.999	1.000	0.251
	Measured round trip time/min	1532	0.997	0.969	1.026	0.845
Diarrhoea	At home water source	2858	0.732	0.487	1.102	0.135
	Any water fetched from out of home	2860	1.479	0.854	2.561	0.162
	Estimated time to source/min	2197	0.998	0.971	1.026	0.909
	Estimated water used/p/d	2411	0.999	0.994	1.004	0.578
	Measured round trip distance/m	1464	1.000	0.999	1.001	0.559
	Measured round trip time/min	1518	1.006	0.972	1.040	0.748

There was no strong evidence of a significant impact on eye disease or diarrhoea of any of the predictors we tested. Measured round trip to source showed a weak impact on skin disease but the effect was small.

3.5. Musculo-skeletal and general health impacts of carrying water

3.5.1. Literature review

A review of literature was conducted in 2012, to identify and evaluate published literature reporting health impacts of carrying water over distance from an out of home or publically share water supply. The full review will be published separately. The findings of this review are summarised below.

Six studies met the inclusion criteria and were deemed relevant to the review topic. Several studies focussed on descriptive statistics related to water carrying and access (Hemson, 2007, Geere et al., 2010a, Thompson et al., 2000); two were qualitative research reports, one on children's health perceptions (Geere et al., 2010b) and the other on gender issues (Sultana, 2009); and a final paper reported pain and rating of perceived exertion on head loading in a laboratory setting (Lloyd et al., 2010). A common conclusion of all studies was that water carrying can impact on general health and pain, but that further research is required. No large scale epidemiological studies were found which had used an appropriate study design to scientifically analyse the association between water carrying or related risk factors and physical health outcomes such as self-report of pain, physical functioning or disability.

3.5.2. Findings from the field study

Descriptive statistics on key health outcomes were generated for adults and children in each country, comparing people with at house water supply to those using shared water supplies. Summary data tables are included in **Appendix E**.

The reporting of pain in hands and upper back was statistically significant for individuals who had previously or who currently carry water. There was also a close-to-statistically significant relationship between water carrying and reported pain in the shoulders/arms, head, chest/ribs and abdominal area.

Interestingly those who previously or currently carry water scored higher on overall ratings of general health than those who had not and this finding was also statistically significant. This may indicate some general health benefits linked to water carrying, which for example, could be derived from better cardiovascular fitness linked to being more physically active, or a greater sense of wellbeing linked to the positive social contribution or interactions associated with water carrying. Such positive health benefits were reported in previous qualitative research conducted with people who carry water (Geere et al. (2010a)).

A factor analysis of different pain location variables aligned well with this general finding; there was a marginally significant negative association between currently or previously carrying water and a set of pain outcomes (in the neck, shoulders/arms, lower back and hips/ pelvis) which are typical of muscle or joint strain. These are likely to be improved through remaining generally fit and active and having regular physical activity such as would be associated with water carrying.

By contrast the factor analysis also resulted in the identification of a specific set of pain outcomes (in the chest/ribs, hands, feet, abdomen/ stomach, head and upper back) which were highly associated with currently or previously carrying water. There is a plausible biological explanation connecting such outcomes with the carrying of water-filled buckets on the head via sustained compressive loading on the spine and upper back. These findings are sufficiently significant to suggest a relationship between water carrying and an increased risk of specific musculo-skeletal related diseases such as cervical spondylosis which merit further investigation.

In summary the data suggest both a mild positive impact on general health for some water carriers as well as a potentially serious negative impact on spinal health via a specific musculoskeletal mechanism for others.

3.6. Water quality

3.6.1. General

Water quality and its relationship to source types, distance to source and storage practices was not part of the terms of reference for this study. However, the team was able to make use of additional funding from another source to take advantage of the fieldwork being undertaken in three countries and to add additional texture to our study. We are also able to report on the findings of a review of literature undertaken by UNC with support from WaterAid.

3.6.2. Literature review

A forthcoming review concluded that improved sources had significantly lower *E.coli* concentrations than unimproved sources Bain et al. (2013). The literature also suggest a view that, despite being less contaminated than unimproved sources, a significant percentage of improved sources have water quality associated with higher health risks. The heterogeneity of source water quality for sources of all types supports the argument that a hierarchical "water ladder" may tend to oversimplify a complicated water safety landscape (ibid.).

A few studies directly comparing water quality from water supplies on premises with those off premises were identified. These found that contamination can be more common among community sources. For example, in urban Nigeria, Ejechi and Ejechi (2008) found 18% of public water sources to be contaminated whereas 6% of private boreholes contained thermotolerant coliform (n=100 for both source types). Similarly, Genthe and Seager (1996) found contamination in community standpipes whereas in house taps were free of thermotolerant coliform in a South African township (n= 153 and 24 respectively). Zuin et al. (2011) did not find significantly more frequent E. coli contamination in community taps than in-house taps in peri-urban area of Maputo, potentially due to the small sample sizes (62 and 27).

3.6.3. Results from the field

Details of the water quality study will be published separately.

Samples were analyzed using the Aquatest method, described in detail on the Aquatest Programme website (Bristol, 2013).

Stored water and source water

When the pooled multi-country data were analysed, it was found that stored water contained significantly ($p<0.05$) higher E. coli concentrations than source water (Table 23, Figure 5). Mean stored water concentrations were 25.2 (95% CI 18-32) CFU/100 mL; while mean stored water concentrations were 62.8 (95% CI 53 - 73) CFU/100. A higher percentage of stored water samples contained concentrations of E. coli in excess of 100 CFU/100 mL. Interestingly, both source and stored water samples with turbidities > 1 NTU tended to have higher E. coli concentrations (turbidity data were available for Ghana only). These effects were significant at the 90% and 95% confidence levels for source and stored water samples, respectively.

Table 23: *E. coli* concentrations in source and stored water from on-plot and off-plot sources

Source Access	Source CFU/100 mL (S.D.) [95% CI]	Stored CFU/100 mL (S.D.) [95% CI]
On-plot	24.32 (61.57) [14.33 - 34.33]	62.52 (88.87) [44.42 - 80.63]
Off-plot	25.99 (65.65) [15.47 - 36.51]	62.94 (89.27) [50.97 - 74.92]
Total	25.17 (63.57) [17.95 - 32.39]	62.82 (89.01) [52.88 - 72.75]
P	0.8213	0.9698

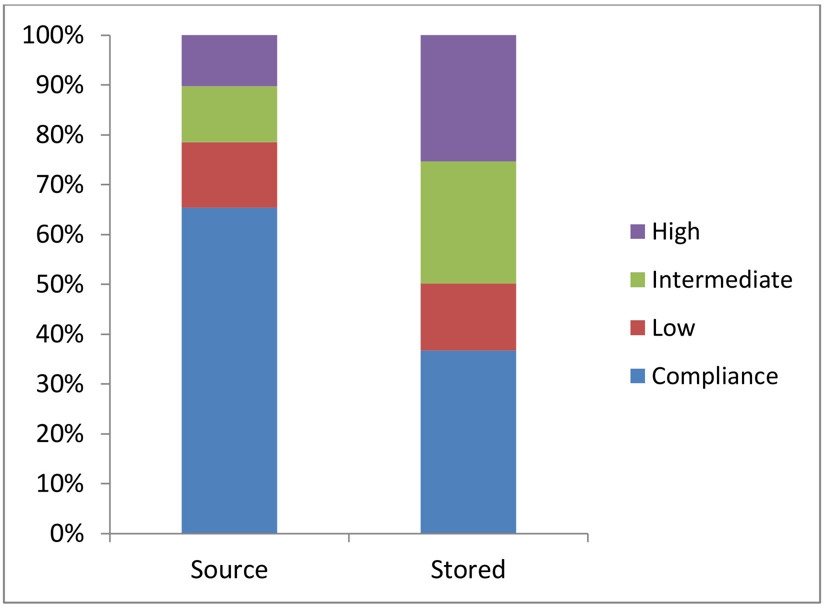

Figure 5: Health-based risk categories of source and stored water samples

Source categories

E.coli concentrations in source water from on-plot sources were not found to be significantly different from those in water from off-plot sources (Table 23). However, source water from improved sources was found to have significantly lower *E.coli* concentrations ($p<0.05$) than water from unimproved sources; interestingly, stored water from improved sources also had significantly less *E.coli* ($p<0.05$) than stored water from unimproved sources (Table 24). Similarly, it was found that source and stored water from on-plot improved sources had significantly lower *E.coli* concentrations ($p<0.05$) than source and stored water, respectively, for other sources (Table 25). Finally, source water samples from household taps was found to contain lower *E.coli* concentrations ($p<0.05$) than water from other sources (Table 26, Figure 6); differences for stored water were not significant.

Table 24: *E. coli* concentrations in source and stored water from improved and unimproved sources

Source Type	Source CFU/100 mL (S.D.) [95% CI]	Stored CFU/100 mL (S.D.) [95% CI]
Improved	12.27 (45.61) [6.53 - 18.01]	55.44 (85.81) [44.80 - 66.09]
Unimproved	82.61 (94.12) [57.17 - 108.06]	94.31 (96.08) [69.27 - 119.35]
P	0.0000	0.0024

Table 25: *E. coli* concentrations in source and stored water from on-plot improved sources and all other sources.

Source Access	Source CFU/100 mL (S.D.) [95% CI]	Stored CFU/100 mL (S.D.) [95% CI]
On-plot Improved	8.62 (39.06) [1.53 - 15.71]	37.31 (71.52) [19.86 - 54.75]
Other	36.05 (73.56) [25.26 - 46.84]	69.82 (92.14) [58.20 - 81.44]
P	0.0002	0.0079

Table 26: *E. coli* concentrations in source and stored water from on-plot piped sources and all other sources.

Source Type	Source CFU/100 mL (S.D.) [95% CI]	Stored CFU/100 mL (S.D.) [95% CI]
At-home piped water	0.31 (0.82) [0.01 - 0.61]	31.44 (89.51) [53.89 - 74.26]
All other sources	28.04 (66.55) [20.05 - 36.02]	61.07 (71.45) [-13.96 - 76.84]
P	0.0212	0.2136

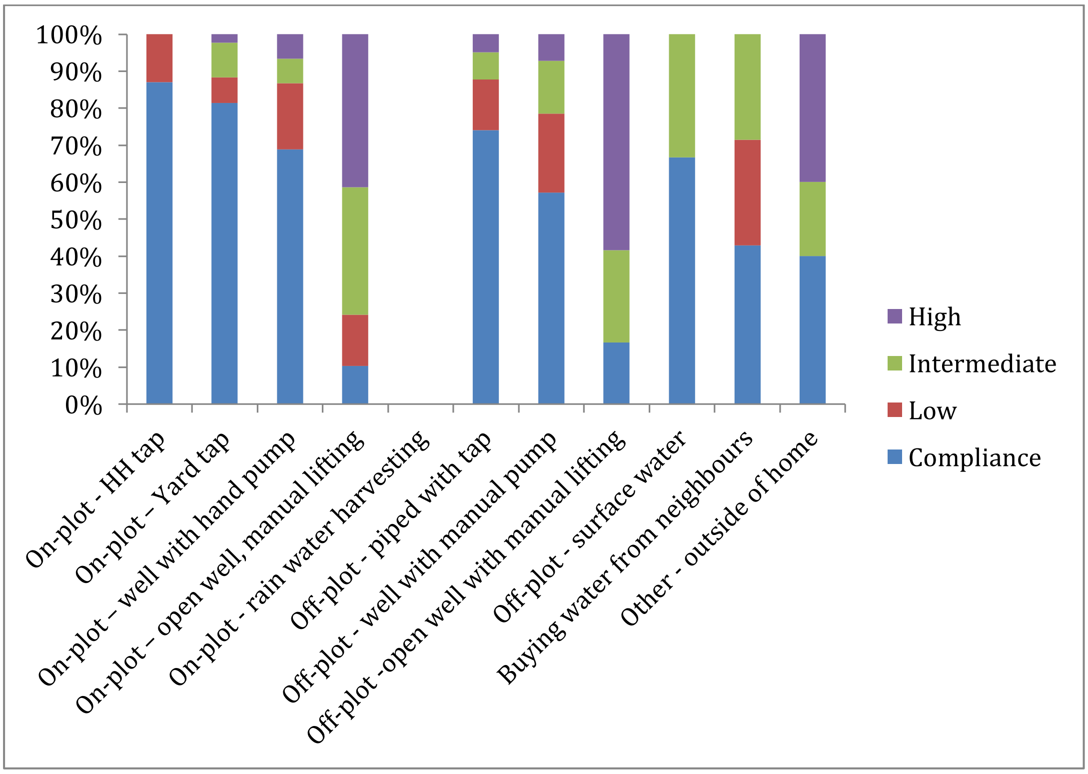

Figure 6: Health-based risk categories of *E. coli* concentrations for source and stored water from various sources.

Individual source types

A pairwise comparison of all source types showed significant differences between several different types of sources. Most notably, source water from open wells, both on-plot and off-plot, was significantly ($p<0.05$) more contaminated than water from all on-plot improved sources, as well as off-plot piped water and water purchased from neighbours (generally also piped) (Table 27**,** Figure 6). No significant differences in water quality were observed between samples of stored water from different sources.

Distance and time to source

There were no significant effects of distance or time to source on *E.coli* concentrations in source or stored water. Specifically, across log distance quintiles and log time quintiles, *E. oli* concentrations were not significantly different at the 95% confidence interval (Table 28**,** Table 29).

Table 27: *E. coli* concentrations in source and stored water from various sources

Source Type	Source Group CFU/100 mL (S.D.)	Stored Group CFU/100 mL (S.D.)
On-plot - HH tap	A 0.31 (0.82)	A 31.44 (71.45)
On-plot – Yard tap	AB 6.81 (35.19)	A 39.00 (74.77)
On-plot – well with hand pump	AB 16.08 (52.92)	A 2.23 (4.40)
On-plot – open well, manual lifting	CD 88.78 (90.10)	A 122.87 (98.16)
On-plot - rain water harvesting	. .	A 114.5 (64.35)
Off-plot - piped with tap	AB 15.69 (51.43)	A 54.92 (85.80)
Off-plot - well with manual pump	ABC 23.19 (61.72)	A 44.81 (74.51)
Off-plot -open well with manual lifting	D 137.04 (102.44)	A 93.79 (96.35)
Off-plot - surface water	ABC 17 (29.44)	A 127.82 (100.65)
Buying water from neighbors	AB 5.4 (8.29)	A 29.49 (75.57)
Other - outside of home	BCD 88.2 (102.72)	A 25.46 (59.44)

Note: *Vertical groups sharing a letter are not significantly different at the 95% confidence level*

Table 28: Log travel time to source and water quality

log time quintile	Stored Group CFU/100 mL (S.D.)
1	A 68.04 (95.46)
2	A 67.25 (89.00)
3	A 67.85 (88.23)
4	A 51.98 (87.32)
5	A 49.74 (79.60)
Kruskal-Wallis p	0.662

Table 29: Log distance and water quality

log dist quintile	Stored Group CFU/100 mL (S.D.)
1	A 74.57843 (96.11415)
2	A 68.52069 (96.44541)
3	A 56.8 (87.10228)
4	A 47.32131 (73.64256)
5	A 36.45185 (73.61668)
Kruskal-Wallis p	0.3605

Health impacts

When the cross-sectional prevalence of skin infections, eye infections, and diarrhoea, as well as missed days of school or work were compared across water quality categories (by presence/absence of *E.coli*), only one significant effect was observed; detectable *E.coli* in source water samples was found to be associated with someone in the household missing school or work due to illness.

Country-specific Results

In both Ghana and South Africa, as in the multi-country analysis, stored water was significantly more contaminated than source water, while differences in *E.coli* concentrations between on-plot and off-plot sources were not significant. Source water samples from household piped sources were significantly less contaminated than samples from all other sources, while there was no significant difference among stored water samples. In Ghana, both stored and source water from improved sources was significantly less contaminated than stored and source water, respectively, from unimproved sources. Comparisons between improved and unimproved sources were not possible for South Africa, as only 5% of samples were collected from unimproved sources. Finally, in Ghana, source water from all sources except on-plot open wells with manual lifting was found to be significantly less contaminated ($p<0.05$) than source water from off-plot open wells with manual lifting. In South Africa, the only significant difference observed was that source water from at-home taps was significantly less contaminated ($p<0.05$) than samples from sources classified as "Other", primarily tanker trucks. There were no significant differences among stored water samples in either Ghana or South Africa.

Conclusions

The results of this work suggest that on-plot improved water supplies in general, and household piped water connections in particular, result in lower rates of *E.coli* contamination than other sources, particularly unimproved sources such as open wells, both with respect to source water and stored water.

3.7. Social benefits of at-house supplies

The field research generated information about what activities were carried out by household water carriers and former household water carriers over a 24 hour period. The activities described were then clustered as follows:

- Social activities: Drink and Eat, Religious and spiritual activities, Spending time with other people, "Phone calls, letters, emails, internet, video games", Playing, Playing sports, and Visits / meeting
- Personal hygiene: Dressing, getting ready, Bathing and Going to the toilet
- Domestic: Washing (dishes and / or clothes), Preparing to eat, Other domestic activities, Purchases (at the market, etc.), Taking care of other members of the household
- Employed work: Work and activities related to work (going to work, finding a job etc) and Professional training
- Inactivity: Sleep, Resting, Watching television

We carried out a multivariate regression which indicated that inactivity, employed work and personal hygiene were significant within the multivariate regression. However, when we looked at the predictors of these activities the only significant association was between carrying water and 'inactivity'. People who collect water had about 40 minutes less inactivity time than those who did not.

The finding that reduced time carrying water is not significantly correlated with increased economic activity bears out similar recent findings (Devoto et al. (2012)). However there is a plausible case to be made for the benefits of increased 'rest' time which may also be in part defined by time spent with the family and in particular time spent by parents with children in non-work activities. This could be linked to intergenerational effects; children who have the opportunity to spend more time with their parents may have improved opportunities for learning and this may have knock-on effects in their own adult lives. This intergenerational impact of reduced time for children or parents spent collecting water merits further investigation.

4. Discussion

We carried out a mix of secondary and primary research to examine the hypothesis that access to an at-house water supply will deliver significantly greater health, social and economic benefits than those derived from a shared public water supply.

The relationship between water source, water usage and health and social outcomes is complex and mitigated by range of contextual and intermediate factors. A recent review of global data sets for example suggests that time spent walking to the household's main water source was a strong determinant of under-five child health (Pickering and Davis, 2012). However a review of this analysis suggests that alternative interpretations would be possible if the data were to be adjusted for other water- and sanitation-related variables or for a broader set of determinants of these multiple child health outcomes. In general it is likely that households experience a clustering of risk factors so that simply looking at water fetching time in the analysis without adjusting for type of water source, type of sanitation facility, type of cooking fuel masks specific effects and the outcome is more likely to be a measure of general "environmental deprivation" rather than the specific effect of water fetching time.

A fundamental challenge in comparing outcomes of at-house supplies with shared supplies lies with wealth as confounder. In our analysis we were able to account wealth effects to some extent because of the detailed household information we were able to collect. Nonetheless these challenges are significant.

In our research we focused on a two-step approach, looking at the relationship between distance to source and volumes of water consumed followed by an analysis of volumes of water carried/consumed and health and social outcomes, including hygiene practices. In this way we hoped to reduce the effect of wealth and other broader social contextual factors in the analysis. This was supplemented by the analysis of the relationship between source-type and water quality.

From our field data a strong theme was the heterogeneity of water sources used by many households. This dimension of water usage has received only limited attention from researchers although our findings did align well with earlier work carried out in urban Uganda (Howard et al., 2002). The diversity of multiple use strategies is much greater than the literature in general suggests. It is likely that the use of multiple sources of water for different activities is a significant confounder and one of the reasons why research into the relationships between health outcomes and use of specific water sources has been inconclusive.

We found a strong link between volumes of water consumption and the at-home-off-plot break point in services but limited evidence of a distance-volume relationship once households were using off-plot supplies. We also found some evidence to suggest that, where reliability of services is poor, the location of the water source may be less significant than its performance characteristics. In our study locations we found some evidence of households who access water from both private and public wells collecting higher quantities of water than users who access water from taps. Similarly we found strong evidence of a 'break point' in health outcomes between those who carried, or who had previously carried, water from outside the house and those who did not particularly relating to musculo-skeletal effects.

Water quality was significantly better for those with piped water at home that those who carried water from elsewhere and stored it at home. The evidence on social benefits was limited but points to possible advantages to families who do not have to spend time carrying water but can spend time in leisure activities.

Overall the results from our research indicate that evidence for the detailed water quantity versus distance to source curve is tenuous. The conclusion that at-house supplies are associated with higher consumption and health and social benefits is supported but there is no evidence for the secondary drop in consumption at a fixed distance from home. In reality it seems most likely that the relationship between distance to source and volumes of consumption is likely to be highly mediated by social and geographical factors, with the curve likely to be 'displaced' upwards or downwards in different contexts. This research has highlighted a number of important gaps in the literature and indicates that the relationships between dimensions of water provision and health and well-being merit further investigation.

Further work and publications

The study team has planned a series of publications arising from then study. A preliminary publication list is indicated below with indicative target dates for publication and possible journals indicated in brackets:

(i) Review of International and National Targets and Standards (December 2013, JWASHDev)
(ii) Relationship between distance to source and water quantity (November 2013, IJERPH)
(iii) Water quality aspects of source types and distance to source (January 2014, WST)
(iv) Effect of at-home water supplies on hygiene behaviours - A review of literature (November 2013, IJTMH)
(v) Distance to source and health impacts – a review of literature (January 2014, Bull.WHO)
(vi) Relationships between distance to source and MSK effects (February 2014, Journal to be identified)
(vii) Synthesis study report (update of Howard and Bartram, 1993) (December 2013, Bull. WHO)

5. Conclusion

The headline conclusion from our research is that at-home water supply has significant, measurable benefits when compared with shared water supply outside the home provided that the service provided is reliable enough to ensure access to adequate quantities of water when required. Reliable at-home water supply results in higher volumes of water consumption, greater practice of key hygiene behaviours, a reduction in musculo-skeletal impacts associated with carrying water from outside the home, and improved water quality.

This suggests a logical policy shift towards the promotion of reliable household access as the international benchmark for water supply.

For many governments, the implications of this are relatively simple. Where most people have access to reasonable quantities of water close to the home, there is a strong and compelling argument to focus investment in getting reliable water supplies into the home. In such cases, the outstanding challenges relate to improving our understanding of the relative risks associated with dimensions of levels of service. For example, under what circumstances does a tap in the house have significant benefits over a tap in the yard? What is the relative risk associated with intermittent supply or low pressure of at-house piped supplies compared with private wells or shared supplies, if the latter can provide a more reliable service? A pressing gap in the literature relates to the water resources and cost implications of providing 24 hour supply in piped systems.

For some countries however, the challenge of moving to household supply as the benchmark level of service is more significant and will take time. In these locations (typically arid regions with limited water resources and limited access to capital funds) the policy emphasis may change more slowly. The clear policy message is that investments in water supply should be designed to enable a progressive move towards provision of household supplies even if this level of service cannot be achieved immediately. This might mean for example, designing point-source systems in such a way as to facilitate the addition of networks and house connections at a later date.

In the post-2015 era, the available evidence suggests that access to water supply at-home should be the benchmark for water supply.

Appendix A: Field work report: Ghana

Study Area and Communities

Four communities (Table A-1) near Kumasi in the Ashanti region of Ghana were included in the DFID field study. All four communities were centred around a main road, stretching out densely along the road and less densely outward from the road on either side.

Table A-1. Ghana study community characteristics.

Town Name	Density	Population 2012	No. of registered users (GWC)	No. of HHs in Survey
Nkawie (a town)	Urban	9, 054	528	67
Asuofua (a town)	Peri-urban	8, 373	132	61
Barekese (a town)	Peri-urban	10, 544	---	63
Abuakwa (a small city)	Urban	23, 634	---	64
Total				255

Household Characteristics

The definition of "household" in the Ghanaian context is also distinct from the definitions applicable in other countries. Households in the study communities lived almost exclusively in compounds comprised of 3-6 nuclear family units living in adjacent rooms that formed a larger structure with a shared courtyard. These family units were often but not always biologically related to each other. Enumerators were trained to collect data from a single family unit within each compound to avoid confusion. For the purpose of this study, a single water source used exclusively by the households within a single compound was classified as a private source. Since only one household was interviewed in each compound, respondents with private sources were asked to report the total number of individuals sharing the source. If a water bill was available for that source, the previous month's consumption was divided by the total number of users reported to calculate the average per-capita consumption.

In addition, it was observed during training that Ghanaians often use the words for "sister" and "brother" figuratively for close friends and familiar cousins, and often use "husband" and "wife" figuratively to refer to their husband's brothers or their wife's sisters. Thus, enumerators were instructed to clarify the actual biological relationships among household members when administrating questionnaires.

Water Points and Water Collection

Some households in the study area were served by private connections provided and maintained by the Ghana Water Company Limited (GWCL, responsible for water supply in urban areas and some small towns in Ghana), while others used public water sources, largely provided by local government (District Assemblies), with support from the Community Water and Sanitation Agency (CWSA). Other households used private boreholes and piped sources that may have been installed by local government or by the users, and some used hand-dug wells, presumably installed by the users. Households included in the study that were serviced by GWCL were asked to share their previous month's water bill, and the previous month's water usage was recorded. Consumption by non-GWCL users was estimated based on observed container volume and self-reported collection frequency. All four communities contained a mixture of private and public supplies shown in Table A-2.

Table A-2. Primary water sources used by households in study communities.

	Number of Households				
	Nkawie	Asuofua	Barekese	Abuakwa	Total (%)
Household tap	2	2	1	3	8 (3%)
Yard tap	6	15	21	15	57 (22%)
Private well, motorized pump	0	0	0	4	4 (2%)
Private well, manual lift	16	5	7	8	36 (14%)
Total Private Sources	24 (36%)	22 (36%)	29 (46%)	30 (47%)	105 (41%)
Communal tap	22	36	30	24	112 (44%)
Communal covered well, manual lift	8	0	3	9	20 (8%)
Communal open well, manual lift	13	3	1	1	18 (7%)
Total Public Sources	43 (64%)	39 (64%)	34 (54%)	34 (53%)	150 (59%)

No households reported using rainwater for drinking and domestic purposes. A mistranslation in the survey questionnaire resulted in “rainwater collection” bring translated as simply “rain” in the local language, but field observations of the communities did not reveal evidence of any households using rainwater collection methods of any kind.

A substantial number of respondents also reported obtaining drinking water in the form of “sachets,” or 500-mL plastic water bags produced by commercial manufacturers and sold in most shops and by ubiquitous street vendors for 0.10 GHS (equivalent to USD $0.05). While these were not the primary source of water for domestic purposes, they provided a convenient and readily accessible drinking water source.

Household interviews also revealed the sharing of some private supplies amongst households, creating an added level of complexity in determining ownership of and access to water supplies. In cases where a respondent used a neighbours’ “private” source (usually for a fee comparable to that for public sources), that respondent was considered to be fetching water from a public supply. In cases where a respondent shared their own “private” source with neighbours, however, the respondent was considered to be accessing her own private supply when she fetched water. These decisions were made based on the relative proximity, access, and control users had to their own “private” source vs. their neighbours’ source. The notion of “public” and “private” sources was further complicated in a small minority of households, where respondents with water sources on their properties reported that the government had given them “private” supplies to be used by their communities.

Some respondents were also unsure as to the type of primary drinking water source they used, as they hired other women in the community to fetch water for them. These respondents were similarly unable to show enumerators where they fetched the water, preventing measurement of the distance travelled and time spent fetching water. This finding was of interest, as delivery of water from public sources by others had not been considered in the study design. This mode of water collection is unique because the physical and time burden of water collection shifts from the household to an outside water carrier. A properly controlled comparison of domestic and professional water carriers in relation to musculoskeletal outcomes could be of interest with respect to the health impacts of water carriage.

Most respondents reported paying to access water. Users of public and shared private sources typically paid a small fee to fetch water, typically ranging from GHS 0.05 (USD $0.025) to GHS 0.10 (USD $0.05) per trip, with users typically being allowed to fetch 20-60 L of water per trip. Users fetched water in a large variety of containers, but the most commonly used vessels were 20, 30, or 40-L round plastic or metal basins, followed by 20-L jerricans and 15 or 20-L buckets. Most adult water carriers were observed to fetch between 15 and 40 L per trip, while most children fetched 10-30 L. Professional water carriers typically fetched 40-60 L per trip in large basins. Most users transported water by balancing one container on their head, cushioned by a ring of folded cloth. Users fetching water from a well with a manual pump or manual lifting would fill a container, then lift it onto their head, usually with the help of another user waiting to collect water. Where piped water was available from public standpipes, community members often modified these standpipes with an additional length of pipe, so that water could be dispensed from the original faucet to fill a narrow-mouthed jerrican on the ground, or from the extension pipe, at a height of approximately 2 m, allowing the user to fill a basin or bucket while it was balanced on the head.

Wealth Data

In Ghana, it was observed that many households reported extremely low or non-existent incomes when asked directly about their earnings, in contrast with significant water costs and the ownership of mobile phones, etc. Anecdotally, one Ghanaian colleague mentioned that rural Ghanaians are often very circumspect about their finances, and will frequently under-report income and possessions to avoid provoking envy or discomfort among their neighbours. Thus, it is possible that the apparent disparity between reported incomes and consumption patterns may be related to this cultural bias.

Appendix B: Fieldwork report – Vietnam

Study area and communities

Four villages in the province of Lao Cai were included in the field study. The villages are in a remote rural area close to the border with China in the north of Vietnam. The area is mountainous and experiences a cold dry season from October to April and a tropical monsoon season from April to September. The province is one of the poorest in the country, with an estimated expenditure and income poverty incidence of 54% (REF).

Four communities were included in the study (**Table B-1**)

Table B-1: Vietnam study community characteristics

	Number of households	Number of HHs in the survey
Trạm Thải	72	50
Lắp máy	67	43
Phân Lân	68	55
Láo Lý	57	51

Sampling of households was hampered by the fact that available local records, provided by the district health posts, were unreliable. Local village leaders felt that more than half the data provided by the district was out of date or otherwise inaccurate. Sampling in any community therefore had to be based on a revised household list prepared in consultation with local leaders.

Láo Lý was reportedly a much poorer environment than the other three communities, with evidence of widespread open defecation and indiscriminate solid waste dumping. The quality of housing was reportedly poorer, with more common use of low cost materials such as masonry breeze blocks or thatch rather than bricks and tiles. The other three communities were reportedly clean with only minor evidence of littering.

Household characteristics

The average household size was 4.1 and the maximum number of people in any study household was 11. The area is highly ethnically diverse, with at least five ethnic groups represented in the survey. These were Day, Tay, Dao, Mong and Kinh. The Kinh group are reportedly the 'senior' community and generally live lower down the mountainside with other groups higher up.

Water use

Most of the study area has been provided with gravity piped water supply systems through the Government of Vietnam's 'Programme 135'. These systems generally draw water from springs or streams higher up the mountain and deliver it to individual households. The water is often stored in a concrete tank in the house or yard. Households widely reported that this water is 'not clean' or 'not enough'. During the rainy season the water is reportedly 'dirty' and this was confirmed by our enumerators who observed high rates of suspended solids in the gravity scheme water. An inspection of the source for some of these schemes confirmed that the protection of springs and surface sources is rudimentary. Many households who had connections to these systems supplemented their supply with shallow wells, 2-3m deep, located within the yard, and this was often reportedly preferred as a source of water for drinking and cooking. Unusually for Vietnam rainwater harvesting systems were not prevalent in the area; households reported that rainwater is scarce.

Most of the gravity piped supplies in the area have been installed relatively recently. In village Phân Lân a system was installed during the period of the research. Households appeared to have good knowledge of the location of the source. The sources were often fairly distant from the households and access was via steep narrow paths.

Overall 43.9% of the respondents reported piped water to the house or yard as their main source of supply, 25.8% reported a well as the main source and 19.2% a shared supply of surface water. The latter may include water piped into the house from a distant source. Overall 76.8% of households reported that their main supply was outside the house but this often referred to water from elsewhere that was piped into the house or yard. Since most households used multiple sources of water for different uses it was difficult for many households to say with confidence which was their 'main' supply.

31.3% of households reported carrying water from outside the home and this was usually carried manually but not on the head.

Piped water supply is supposedly metered although we were not able to confirm the presence of meters during the fieldwork. In focus group discussions the general impression was that there was a willingness to pay for piped water but that the quality and quantity of the water was inadequate. Households reported that in the new scheme in Phân Lân water would be free up to 3,000 l per month per household. It was observed by participants in focus group discussions that this amount was quite low, particularly for rural households with livestock.

In Phân Lân, Lắp máy and Trạm Thải water was reportedly boiled before drinking although not in Láo Lý. This result could not be confirmed during household interviews.

Appendix C: Fieldwork report - South Africa

The study was conducted over a period of 10 weeks (late September to early December, 2012) in three peri-urban communities in Vhembe District in the northern parts of Limpopo Province in South Africa. Three communities were selected from a sample frame of ten, that represented water service levels in the area (**Table C-1**).

Table C-1: Private and shared water supplies in the study communities

Community	Households with shared supply	Households with private supply	Total number of households
1	406	56	462
2	741	84	825
3	467	359	826

Communities 1 and 2 (C1 and C2) are located in the dry, flat area west of Makhado / Louis Trichardt town. .The water sources in Communities 1 and 2 (C1 and C2) are communal taps or private drilled wells with either a yard tap or in-house connection. Community 3 (C3) is located in the foothills of the Soutpansberg mountain range. Shared water sources in the area are protected springs and communal taps, while private supplies are yard taps or in-house connections.

Although all three communities had problems reliability of water supply, the supplies C1 and C2 seemed to be particularly unreliable. Most of the households using communal taps as their main source reported their alternative source as buying from neighbours with private drilled wells, and a few more relied on a municipal tanker that delivered water to the area once a week.

Although the households in C1 and C2 bought water from neighbours with drilled wells, a common complaint was that the water from these wells was very salty. This is not surprising, as the two communities are located at the base of the Soutpansperg ("salt pan mountain") mountain range. Because the water was so salty, some households with private supplies reported using communal taps or a municipal tanker that delivered water once a week as alternative sources, mainly for their drinking water.

Thus the 'private' supplies in C1 and C2 were private in the sense that they were wholly managed by the households themselves. By drilling their own wells and setting up yard or house connections and in some cases subsequently selling water to their neighbours, these households performed the role 'service' roles of abstraction and distribution roles themselves.

The relatively wealthier households in C3 did not drill wells, but paid for a municipal connection to the yard / house, or privately connected pipes from the protected springs in the area to the yard / house. Some households with municipal connections still collected drinking water from springs, as they preferred the taste of the water from there. During water supply failures, households using communal taps collected water from either the nearest springs, or from neighbours with connections from the spring. Unlike in C1 and C2, water collected from neighbours in C3 was obtained for free.

Appendix D: Field work analysis – supplementary data

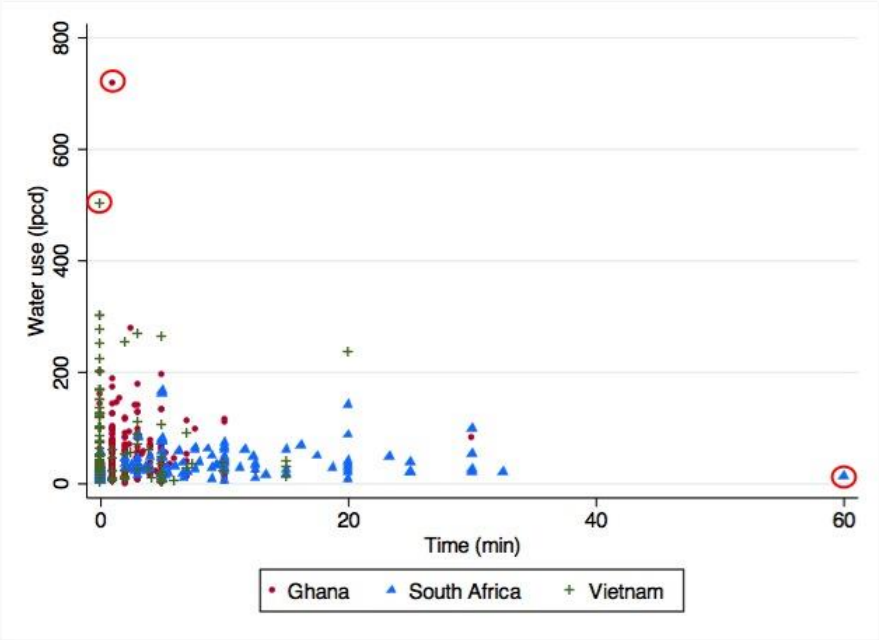

Figure D.1. Scatterplot of water use (lpcd) and self-reported one-way travel time to the primary water source for households in all three countries. Extreme data points are circled in red.

Appendix E: Musculo-skeletal health outcomes

Analyses for physical health outcome of pain reported in the previous 7 days, pain location and self-rating of general health were done using Generalised estimating equations (GEE) adjusted for age and sex and accounting for clustering at the household and country level. Where the outcome variable was binary we used negative binomial regression with a log link. Where the outcome variable was scalar we used linear regression models. Personal history of carrying water (current, previous, or no history) was used as the predictor variable, as the descriptive statistics indicate that categorisation into at-house or shared supply does not distinguish between people with different levels of exposure to water carrying.

Report of pain in the hands and upper back were statistically significant, whilst report of pain in the shoulders/arms, head, chest/ribs and abdominal area were close to statistically significant, with increasing relative risk for pain in these locations in people who previously and currently carry water (**Table E-1**).

Table E-1: Reported presence of pain by whether person current carries water, previously used to carry water or had never carried water adjusted for age and sex.

Health outcomes	Predictors	Response category	N	RR	L95%CI	U95%CI	P
Report of pain in the previous 7 days							
Adults reporting pain	History of carrying water	No History	130	1			0.962
		Previous	145	0.97	0.77	1.23	
		Currently	329	1.00	0.82	1.23	
Children reporting pain	History of carrying water	No History	228	1			0.640
		Previous	11	NA			
		Currently	139	0.89	0.55	1.44	
Locations of pain							
Abdominal pain	History of carrying water	No History		1			0.082
		Previous		1.43	0.76	2.69	
		Currently		1.70	1.07	2.69	
Chest/rib pain	History of carrying water	No History		1			0.054
		Previous		1.60	0.71	3.60	
		Currently		2.13	1.14	4.00	
Feet	History of carrying water	No History		1			0.394
		Previous		1.70	0.74	3.91	
		Currently		1.55	0.77	3.13	
Hands	History of carrying water	No History		1			0.020
		Previous		3.62	1.34	9.75	
		Currently		3.11	1.34	7.23	
Head	History of carrying water	No History		1			0.071
		Previous		1.16	0.67	2.02	
		Currently		1.53	1.03	2.27	
Hips/pelvis/legs	History of carrying water	No History		1			0.373

		Previous		1.13	0.74	1.72	
		Currently		0.85	0.61	1.20	
Lower back	History of carrying water	No History		1			0.828
		Previous		0.86	0.53	1.40	
		Currently		0.96	0.68	1.38	
Neck	History of carrying water	No History		1			0.512
		Previous		1.26	0.74	2.16	
		Currently		0.95	0.62	1.45	
Shoulders/arms	History of carrying water	No History		1			0.053
		Previous		0.91	0.52	1.60	
		Currently		0.59	0.38	0.92	
Upper back	History of carrying water	No History		1			0.017
		Previous		2.27	1.17	4.40	
		Currently		2.16	1.25	3.73	

A statistically significant relative risk of better ratings of general health in those who previously or currently carry water was found (**Table E-2**). This may indicate some general health benefits linked to water carrying, which for example, could potentially be derived from better cardiovascular fitness linked to being more physically active, or a greater sense of wellbeing linked to the positive social contribution or interactions associated with water carrying. Such positive health benefits were reported in previous qualitative research conducted with people who carry water (Geere et al. (2010a)).

Table E-2: Impact of water carrying history on self-rated general health (negative scores=increasing sense of health)

Health outcome	**Predictor variable**	**Response category**	**N**	**Regression parameter**	**L95%CI**	**U95%CI**	**P**
Rating of general health today (adults)	History of carrying water	No History		0			<0.000001
		Previous		-0.58	-0.80	-0.35	
		Currently		-0.91	-1.12	-0.70	
Rating of general health today (children)	History of carrying water	No History		0			0.003
		Previous		0.39	0.02	0.75	
		Currently		-0.20	-0.37	-0.31	

Factor analysis

Because reporting of pain at different sites was correlated, we undertook a factor analysis of the different pain location variables. It can be seen that factor 1 is correlated to pain in the chest/ribs, hands, feet, abdomen/stomach, head and upper back, whilst factor 2 is correlated with pain in the neck, shoulders/arms, lower back and hips/pelvis or legs (**Table E-3**).

Table E-3: The rotated component matrix for first two factors of pain location variables, explain 54.8% of variance within the data.

Rotated Component Matrix[a]

Survey q28: Pain location	Component	
	1	2
Abdomen/stomach	.632	.131
Chest/ribs	.706	.151
Feet	.695	.221
Hands	.706	.266
Head	.616	.272
Hips/pelvis or legs	.179	.757
Lower back	.223	.750
Neck	.340	.696
Shoulders/arms	.238	.790
Upper back	.608	.347

Extraction Method: Principal Component Analysis.
Rotation Method: Equamax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

GEE with linear regression was then repeated for each factor and adjusted for age and sex. It can be seen that factor 1 is highly associated with currently or previously carrying water whereas factor 2 is marginally significantly negatively associated. There is biological plausibility in both the correlation of pain areas in each factor and the associations with water carrying. Sustained compressive loading through the cervical spine and upper back, as occurs with carrying water filled buckets on the head, is a plausible mechanism by which intervertebral discs of the cervical and upper thoracic spine may be adversely affected over time, or deformed during loading to compress and irritate other structures (Geere et al. (2010b)) and to cause the correlation of pain locations in factor 1. The pain from cervical degenerative disc disease tends to be in the posterior paraspinal muscles and is associated with headache and inter-scapular (upper back) pain. If degenerative disc disease in the cervical spine (cervical spondylosis) progresses, it can reduce space within the spinal canal to cause irritation or compression the neural tissues (myelopathy or radiculopathy) or their connective tissue coverings. For example early myelopathy due to spinal canal stenosis may mimic carpal tunnel syndrome, causing hand pain or dysaesthesia through dural irritation or neural tissue compression and eventually dysaesthesia in the feet and gait disturbance Clark (1996).

The correlation of pain locations in factor 2 (**Table E-4**), are more typical of simple non-specific musculoskeletal pain due to muscle or joint strain. Neck pain is commonly associated with referred shoulder or arm pain and back pain is commonly associated with pain in the lower quarter (hip/pelvis or legs). Non-specific spinal pain can be improved through remaining fit and active with regular physical activity, such as would occur by regularly walking to a shared water source.

Table E-4: Impact of water carrying history on factor 1 and factor 2

Health outcome	**Predictor variable**	**Response category**	**N**	**Regression parameter**	**L95%CI**	**U95%CI**	**P**
Factor 1 (chest/ribs, hands, feet, abdomen/stomach, head and upper back)	History of carrying water	No History		0			0.000045
		Previous		0.21	0.01	0.42	
		Currently		0.30	0.17	0.43	
Factor 2 (neck, shoulders/arms, lower back and hips/pelvis or legs)	History of carrying water	No History		0			0.023
		Previous		-0.03	-0.25	0.19	
		Currently		-0.18	-0.32	-0.04	

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