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Systematic Review

Measuring domestic water use: a systematic review of methodologies that measure unmetered water use in low-income settings

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Abstract

OBJECTIVE To present a systematic review of methods for measuring domestic water use in settings where water meters cannot be used.

METHODS We systematically searched EMBASE, PubMed, Water Intelligence Online, Water Engineering and Development Center, IEEExplore, Scielo, and Science Direct databases for articles that reported methodologies for measuring water use at the household level where water metering infrastructure was absent or incomplete. A narrative review explored similarities and differences between the included studies and provide recommendations for future research in water use.

RESULTS A total of 21 studies were included in the review. Methods ranged from single-day to 14-consecutive-day visits, and water use recall ranged from 12 h to 7 days. Data were collected using questionnaires, observations or both. Many studies only collected information on water that was carried into the household, and some failed to mention whether water was used outside the home. Water use in the selected studies was found to range from two to 113 l per capita per day.

CONCLUSION No standardised methods for measuring unmetered water use were found, which brings into question the validity and comparability of studies that have measured unmetered water use. In future studies, it will be essential to define all components that make up water use and determine how they will be measured. A pre-study that involves observations and direct measurements during water collection periods (these will have to be determined through questioning) should be used to determine optimal methods for obtaining water use information in a survey. Day-to-day and seasonal variation should be included. A study that investigates water use recall is warranted to further develop standardised methods to measure water use; in the meantime, water use recall should be limited to 24 h or fewer.

keywords water, water supply, hygiene, diarrhea, environmental health, public health

Introduction

Water, hygiene and sanitation (WASH)-related diseases account for an estimated 1.5% of the world's total burden of disease, and the majority of this is shouldered by low- and middle-income countries [1]. The accurate measurement of household water used for domestic hygiene – defined here as all types of cleaning, washing and bathing that is done by the members of a household – is important to better understand its association with WASH-related health outcomes. This importance is highlighted in the Sustainable Development Goals, which has recently focused more on water access than the earlier Millennium Development goals [2].

A number of literature and systematic reviews have documented the health benefits of improved water quality as well as of increased water use [3–5]. A meta-analysis of the effects of water supply interventions on diarrhoeal diseases among young children around the world found that improvements in water availability resulted in a 25% reduction in diarrhoea rates, improvements in water quality resulted in a 16% reduction in diarrhoea rates, and improvements in both water availability and water quality resulted in a 37% reduction in diarrhoea rates [3]. There are several tested and accepted methods to measure water quality, which have been executed in numerous studies [6]. However, standard methods for measuring water use (defined as total water use for all non-agricultural, domestic purposes) in scenarios where water meters are not employed have not been developed.

WHO recommends 50–100 l of water per capita per day (LCPD) to meet domestic needs such as personal hygiene, washing and cleaning [7]. The United Nations Joint Monitoring Programme defines an improved water supply as one that is protected from outside contamination and provides 20 LCPD on average [8, 9]. While an estimated 89% of the world now have access to improved water supply [10], approximately 3.1 billion people worldwide still rely on water that is either unpiped and/or off-premise [11]. It is important to note the distinction between on-premise and off-premise water, as on-premise access has been indicated as contributing to a 60–180% higher per capita water use than off-premise access [12, 13]. As daily per capita use decreases, the risk of faecal–oral and other hygiene-related diseases increases, and people with an average use rate of 20 LCPD are already considered to be at a 'high level of health concern' by the WHO [7].

While it is widely accepted that water availability and use play a key role in maintaining health [7], measuring water use is far from straightforward. The most accurate way to measure domestic water use is through water meters that measure the amount of water used in piped water systems. Yet, in settings where resources and piped water are scarce, water meters may not be an option. Furthermore, in these settings, any combination of factors such as number of water sources used, water storage, seasonal water availability, day-to-day variability, cultural influences on water, water ownership and availability of informants make measuring domestic water use increasingly complex.

Until now, several methods – from direct measurement to estimation and from single-time questionnaires to multiday observations – have been undertaken to attempt to quantify unmetered domestic water use. It is difficult to accurately quantify the impact of water access/use on health outcomes when all of the data to date that link water use to health outcomes are based on non-standardised methods. As such, a review of water use methodologies is warranted to understand what has been done, and to work towards reaching standardised methods for measuring domestic water use. This article presents a systematic review of methods for measuring domestic water use in settings where water meters cannot be used, to make recommendations for future studies that depend on measurements of unmetered water use.

Materials and methods

Search strategy

A systematic review of methodologies for measuring domestic water use was performed according to guidelines established in the PRISMA statement [14]. Between 28 April 2015 and 22 July 2015, eight electronic databases, Science Direct, Embase, PubMed, Elsevier Clinical Key, Water Intelligence Online, Water Engineering and Development Center (WEDC), ScIELO, and IEEExplore, were searched for relevant literature in. In addition, relevant literature was searched in the bibliographies of selected publications.

The literature search included the following keywords and phrases in various combinations: 'water', 'household', 'households', 'domestic', 'water quantification', 'measure water quantity', 'quantify water', 'water consumption' and 'water use'. When a preliminary search in Science Direct produced more than 10 000 results, exclusion terms were introduced to eliminate a high proportion of articles concerning prediction and sustainability modelling, water use in the context of tourism, and hot water use. The final search terms for Science Direct, including Boolean operators, were as follows: ('water quantification' OR 'measure water quantity' OR 'quantify water' OR 'measure water consumption' OR 'domestic water use') AND ('household' OR 'domestic') AND NOT 'heater' AND NOT 'tourism' AND NOT 'tourist' AND NOT 'hot water' AND NOT 'modeling' AND NOT 'modelling'.

Inclusion and exclusion criteria

Any study design in which a method for quantifying water use for all non-agricultural, domestic purposes was described and implemented at the household level was included for further analyses. Studies quantifying water in high-income countries and/or in settings where metered water infrastructure is present; abstract-only publications; studies published in languages other than English, Spanish and Portuguese; studies modelling future consumption or sustainable use; studies investigating industrial or commercial water use, water treatment processes, river discharge, water governance or consumption by animals were excluded. Studies where household-level measurements were obtained indirectly by dividing a community measurement by the number of households in the community were also excluded.

Study selection

This process was undertaken in three phases, first on the basis of titles, then abstracts and finally full text. Titles and abstracts were reviewed independently by two of the authors. Titles including the keyword 'water' or a type of water source, for example, 'tubewell' advanced to the abstract phase of selection. Abstracts containing a phrase suggesting measurement, such as 'water consumption', 'measure water', 'water quantity/ies', or 'water use', and an indicator of household scale, such as 'household', 'domestic', or 'family/ies', were chosen for full-text review. Articles about which the authors disagreed were also read in full. Three authors reviewed 72 full-text articles, selecting those that specified the method of water quantification, quantified water use in a setting where metered water infrastructure was absent or incomplete, and conducted measurements at the household level. Any disagreement between reviewers was resolved through consensus.

Data extraction and quality assessment

A form used for data extraction was piloted on three different studies by three of the authors before making a final decision on which data to extract from the studies. The following data were then recorded into an Excel sheet for each of the selected studies: author; year; title; country where research took place; who was interviewed/observed; who collected the data; rural or urban setting; sample size; time frame; water quantification methods, including details on how, how often, and how long; household water use in litres per capita per day; and additional notes on findings or methods that did not fall under the other categories. The Cochrane Risk of Bias Tool was used for assessing biases in each of the studies [15]. Other potential methodological errors were recorded in the authors' notes on each of the studies. Because the studies' methodologies and results were heterogeneous, a meta-analysis was deemed inappropriate.

Study quality was assessed according to ten criteria reflecting clarity and rigour: clearly described methods, description of ownership of water source, whether water use was presented in a table, whether information was included on whom was interviewed, and/or observed, whether the water use data were presented in a table, whether limitations on measuring water use were discussed, the accuracy of measurement, if observations were used, if water use was stratified by activity, if day-to-day variability was captured, and if seasonal variability was captured. One point was given for each fulfilled quality criterion such that the maximum possible score was 10/10. No points were given for unfulfilled criteria, or where no determination could be made from the text of the article.

Methods were considered clearly described if reproducible based on details presented in the text of the article. Accuracy of water measurement methods was ranked as high, moderate, low or unclear. Accuracy was considered high if water quantities were measured using graduated containers or scales, or when water level changes in water storage containers were determined with the help of a measuring tape. Accuracy was also considered high if data collectors were trained to estimate water container sizes and used some form of direct measurement to validate their estimations as all studies taking this approach reported that the data collectors' estimates closely matched quantities documented through direct measurement [16]. Accuracy was considered moderate if the data collectors were trained to estimate water container quantities without validation by direct measurement. Accuracy was considered low if the method relied solely on self-reported use from the study participants. One point was awarded for high or moderate accuracy, and no points were given for low accuracy. Studies were considered to have captured day-to-day variability if they visited the same household over two or more consecutive days and reported to do so to investigate variability. Studies were considered to have captured seasonal variability by visiting the same households during a different time of the year with the reported purpose of investigating seasonal variability.

Results

A total of 1246 articles were screened by title, and 221 abstracts were selected and read. Next, 72 articles were chosen to be read through entirely. A total of 19 articles met the criteria of describing the methodology of quantifying household and/or individual, unmetered water use. References were mined in the selected articles, which led to the inclusion of two more articles (Figure 1).

The studies were analysed based on water use methodology. Eight studies calculated water use only through means of interviews or self-reporting [12, 16–22]. In one of these studies, household water collectors were trained

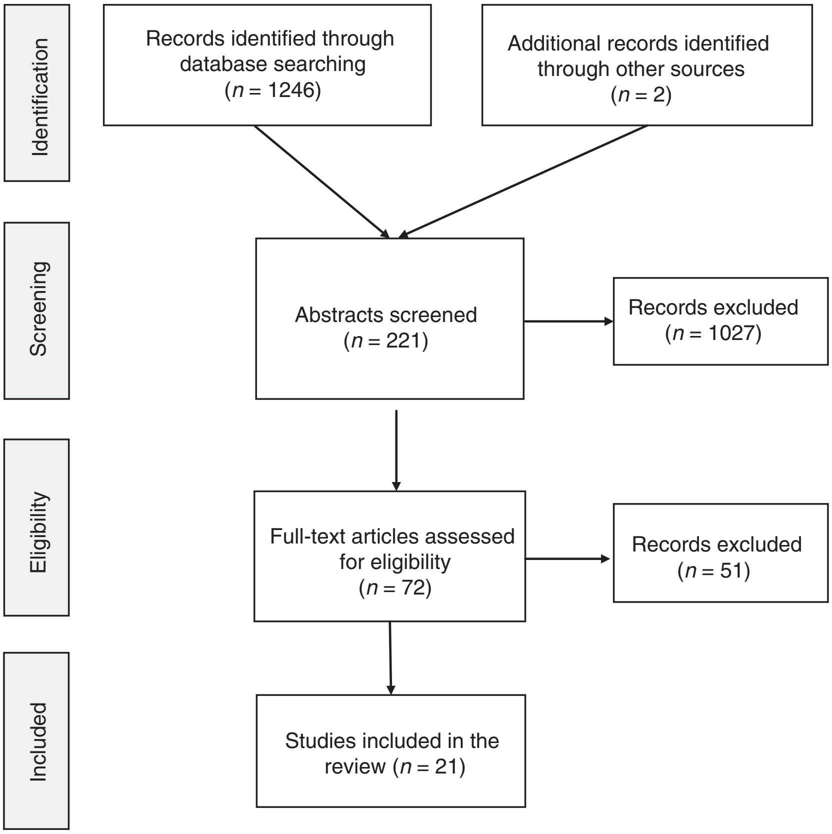

Figure 1 Literature search and selection. PRISMA [14] flow diagram.

to place a stone in a bucket for every time a water container of a known size was filled and a stone in a separate bucket for every ten pumps of a handpump [12]. Another study used pictures of local water containers of known sizes as an aid [19]. Eleven of the 21 studies reported using direct observations in their methodology either exclusively, or with a combination of surveys, interviews or other methods. Four studies reported using observations alone in their methods [23–26], although Hadjer *et al.* [23] included details that implied that unstructured interviews were also used (Table 1).

Of the studies that used questionnaires and/or interviews to collect data, the recall periods varied greatly. Only three studies [27–29] described using twice-daily interviews to ask about water use as one study found that 12 h were the longest period of accurate recall for household water use [30]. Three studies [16, 17, 20] asked about average daily use in questionnaires, while Subbaraman *et al.* [21] used questionnaires to ask study respondents to recall water use for the previous week. Recall bias was hard to assess, given that there were no standardised methods. However, it was assumed that there was recall bias in Subbaraman *et al.*'s [21] study design of a 7-day recall period. The remainder of the studies that utilised questionnaires for collecting water use data focused on an average day, the previous day, or the 24 h before the questionnaire was administered.

Almost all studies relied (at least partially) on counting how many times water collection buckets were filled in order to quantify water use. Five studies measured water quantities directly using a scale or a graduated container in all households or at least a subset of households [13, 20, 25, 31, 32]. Several other studies trained data collectors to estimate the sizes of local water collection vessels or reported that the collection vessels were of a known size [12, 16–19, 21, 22, 27, 28, 33, 34], while others were unclear about how container volumes were obtained [23, 26, 29, 35]. One of the studies that used data collectors' estimates of water container sizes reported that the data collectors were 'highly accurate' in estimating water container capacity although details were not provided [16]. Personal communication with one of the studies' authors (Cairncross, March 2, 2015) revealed that data collectors could be trained to estimate water container capacity within one litre. Therefore, estimation by a trained data collector was considered accurate for the purpose of this analysis.

Table 1 Brief description of setting, sample size, methodology, timeline and water use results of included articles

Article authors and year published	Country	Rural, urban or both	Sample size (where water measurements were taken)	Methodology in brief	Average water use by study participants (as classified in each study): Study participant classifications, if any	Litres per capita per day (LPCD)
Feachem (1973) [32]	New Guinea	Rural	38 households	Questionnaire on the previous day/24 h	Water carried to the households for use	2
Hebert (1985) [20]	India	Urban	Households of 662 children	Questionnaire on the previous day/24 h	Water carried to the households for use	Approximately 11 for cooking and drinking only (washing quantities N/A)
Hoque *et al*. (1989) [24]	Bangladesh	Rural	594 households	Observations from 05:30 to 21:30	Distance to source 0–24 m: 25–49 m: 50–99 m: 100+ m:	 56 49 42 31
West *et al*. (1989) [18]	Tanzania	Rural	'Over 2000' households	Questionnaire on the previous day/24 h	Water carried to the households for use	<25 l/household per day in 30% of households 25–45 l/household per day in 43% of households >45 l/household per day in 27% of households
Blum *et al*. (1990) [26]	Nigeria	Rural	48 households	Observations over the 'course of a day'	Water carried to the households for use	N/A
Mertens *et al*. (1990) [17]	Sri Lanka	Rural	Households of 4950 children	Questionnaire on an average day	Piped supply and non-supply groups	>25 on average across groups. Higher in piped supply group, but quantity not listed
Sandiford *et al*. (1990) [16]	Nicaragua	Rural	1029 households	Questionnaire on an average day	Distance to source: 0–18 m: 18–180 and 180–560 m: 560–1800 m:	 28 19 13
Bailey *et al*. (1991) [25]	Gambia	Rural	118 families	Observations from dawn to dusk plus interview	Water carried to the households for use	17

Table 1 (*Continued*)

Article authors and year published	Country	Rural, urban or both	Sample size (where water measurements were taken)	Methodology in brief	Average water use by study participants (as classified in each study): Study participant classifications, if any	Litres per capita per day (LPCD)
Cairncross & Kinnear (1992) [28]	Sudan	Urban	57 households	Questionnaire on the previous 24 h	Village 1 (vended water):	24.2
				Observations from 06:00 to 18:00 in a subset	Village 2 (vended water; roughly three times more expensive than village 1):	27
Esrey *et al.* (1992) [19]	Lesotho	Rural	Households of 119 infants	Questionnaire on the previous 24 h with pictures	July/August:	10
					January/February:	8
Tonglet *et al.* (1992) [22]	Zaire	Rural	Households of 1096 children	Questionnaire on the previous 24 h	35% of population:	>50 l/household per day
					65% of population:	<50 l/household per day
Cairncross and Cuff (1987) [27]	Mozambique	Rural	329 people	Observations and twice-daily interviews	5-h water collection journey:	4
					10 min water collection journey:	11
Gazzinelli *et al.* (1998) [29]	Brazil	Rural	200 people	Observations from 7:30 to 17:30 for shared water sources	Households that owned a water supply:	25
				Twice-daily interviews for households private water supply	Households without their own supply:	9
Trigg (2000) [35]	Guatemala	Rural	Five villages (unnamed) in Ixil Triangle in Western Highlands of Guatemala	Observations, walking surveys and meetings (timeline unclear). Measurement of community water tanks	Single family yard connection:	84
					Shared communal tap:	42
Tumwine *et al.* (2002) [13]	Kenya, Tanzania, and Uganda	Both	1015 households	Observations from 06:00 to 20:00 and interviews	Single-household piped connection:	58
					No piped connection:	21
Ensink *et al.* (2002) [12]	Pakistan	Rural	30 households	Water recorded by putting stones in a box each time a container was filled or a handpump was pumped 10 times over 24 h. Water tank levels measured	No water connection in homestead	
					In January:	10
					In May:	15
					Connection in homestead	
					In January:	16
					In May:	29
					Connection in homestead + storage tank	
					In January:	48
					In May:	113

Table 1 (*Continued*)

Article authors and year published	Country	Rural, urban or both	Sample size (where water measurements were taken)	Methodology in brief	Average water use by study participants (as classified in each study): Study participant classifications, if any	Litres per capita per day (LPCD)
Hadjer *et al.* (2005) [23]	Benin	Rural	40 households	Observations from 06:00 to 21:00	Intermediate access (range of sources):	>21
					Basic access (village wells):	>19
					No access/basic access (surface water):	>15
García and Brown (2009) [33]	Columbia	Rural	18 households	Observations from 07:00 to 17:00 and interviews	Water used for domestic (non-agricultural) purposes	67
Majuru *et al.* (2012) [34]	South Africa	Rural	114 households	A combination of observations, measurements and semi-structured interviews were used for a 24-h period	Community 1 Handpumps:	14
					After pipe supply:	19
					Community 2 Communal plastic storage tanks:	9
					After pipe supply:	14
Subbaraman *et al.* (2013) [21]	India	Urban	21 households	Questionnaire on water use over the previous week	February:	23
					Early May:	31
					Late May:	26
					August:	24
Oageng & Mmopelwa (2014) [31]	Botswana	Rural	60 households	Questionnaire on the previous 24 h	Water consumed per household:	21

There was a range in both how many times, and how often, study participants were visited in each of the studies. Fourteen studies depended on single-day measurements to calculate water use [6, 12, 13, 16–20, 22, 25, 27, 28, 31, 34]. Seven studies were identified that visited households from 2 to 14 consecutive days to collect water use data in order to account for changes in daily use [21, 24, 26, 29, 32, 33, 35]. It was unclear how many consecutive days of study were used in one of the studies [35]. Two studies also used single-day follow-up visits in a subset of households for validation of results [16, 28], and/or to collect more in-depth water use information [28] (Table 2).

Eleven studies collected data during different seasons [12, 17, 19–23, 26, 32–34]. However, only six of these reported results for seasonal variations in water use [12, 19, 21, 23, 26, 32] (Table 2). One study visited households thrice over the course of 6 months, but they reported that their objective was to evaluate changes in use during different periods of water supply upgrade and did not mention seasonal variation [34] (Table 2).

Domestic water use reported in the studies varied greatly from 2 [32] to 113 LCPD [12] (Table 1). Some studies also found a large amount of variability within their respective study populations, such as Ensink *et al.* [12], who found average use ranged from 15 to 113 LCPD depending on water access level. Five additional studies found that the groups with the highest water access in their respective studies used at least two times as much water as the groups with the lowest access [13, 16, 27, 29, 35]. Two of the studies that explored seasonal changes in water use found a decrease in water use during seasons with less water availability [12, 23], while two other studies found no significant evidence of seasonal variation in water use [19, 21], and the last two studies did not mention variation in water use but did find significant seasonal changes in choice of water source [26, 32].

Selection bias was found in two studies; one in which only participants in communities assisted by NGOs were selected by members of that NGO [35] and another in which a local council of elders was allowed to select the study participants in their respective communities [23]. Methodological error was difficult to assess for individual studies due to the lack of standardised methods. However, there is a potential for bias in all of the studies that did not describe water use other than the water which was carried into the house. Performance bias can be expected in the intervention studies where new water supplies were installed [22, 34, 35], yet this is impossible to avoid, as a resident cannot be blinded to a new water supply system. The vast majority of the studies found a statistically significant association between water access and water use or between water use and health outcomes. This may be indicative of publication bias.

Discussion

In a scenario without water meters, every additional water source used increases the complexity of measuring domestic water use, as every new source is a new site of measurement. Water from different water sources may be collected or used in different ways, for example in buckets or used directly at the source, which can force methods to change depending on how water is extracted and/or transported. Water flow rates may also vary between sources, as for instance 10 pumps at a handpump, or 10 s at a tap stand might yield different quantities at different times of the day. Similarly, quantified water use per activity may not be within the scope of a water supply intervention study. Nevertheless, the end goal should be to quantify water use into litres per capita per day, as 50 LCPD is a general benchmark for water access [7, 36].

This review found that several different methods have been used to measure water use in various low-income settings. Reviews of WASH-related studies have identified over 60 studies that investigated water quality and health outcomes [5, 37–39]. This is nearly three times the number of articles identified on water quantity here, which were not even limited to health outcomes, and elucidates the limited investigation into this important area. The identified applied methods in this review may have both strengths and weaknesses in different settings. However, a lack of standardised methodology, or even a standardised definition of water use, is concerning for any meta-analysis attempting to analyse the impact of water access and its use on health.

Defining water use

Studies must clearly define what water use they measured and how they measured it. For example, some studies only measured water that was carried into the household [19, 26, 27, 32]; a subset of these studies mentioned that bathing and washing – activities which can require large quantities of water – were done outside the home and not included in the measurements. Two studies reported water contact, for example non-consumptive water use for bathing and swimming [12,29]. Although the amount of water used outside the home, for example at a river or a pond, may be unquantifiable, the lack of inclusion may result in decreased total water use measures. Hence, inclusion of all uses of water is critical for defining water

Table 2 Score of components of water use methods in included studies

Authors and year published	Description of methods and limitations					Rigour of water use measurement methods			Explored variations in water use		
	Methodology clearly described	Ownership of water source described	Water use included in a table in results	Explained who was interviewed	Limitations of water quantification discussed?	Accuracy of water measurement†	Included direct observation	Stratified water use by activity	Captured variation from day to day	Captured variation over seasons	Totals
Feachem (1973) [32]	1	1	1	0	1	High	0	1	1	1§	8/10
Hebert (1985) [20]	1	0	1	1	0	–*	0	1	0	–	4/10
Hoque *et al.* (1989) [24]	1	1	1	1	1	High	1	0	1	0	8/10
West *et al.* (1989) [18]	1	0	1	1	0	Low	0	0	0	0	3/10
Blum *et al.* (1990) [26]	1	–	0	1	0	–	1	0	1	1	5/10
Mertens *et al.* (1990) [17]	1	1	1	1	0	Low	1	0	0	0	5/10
Sandiford *et al.* (1990) [16]	1	–	1	1	1	Low	0	0	0	0	4/10
Bailey *et al.* (1991) [25]	1	–	1	1	1	High	1	1	0	0	7/10
Cairncross & Kinnear (1992) [28]	1	–	1	1	1	Mod	1	1	1	0	8/10
Esrey *et al.* (1992) [19]	1	0	1	1	1	Mod	0	0	0	1	6/10
Tonglet *et al.* (1992) [22]	1	1	1	1	0	Mod	0	0	0	–	5/10
Cairncross and Cuff (1987) [27]	1	–	1	1	0	Mod	1	1	0	0	6/10
Gazzinelli *et al.* (1998) [29]	1	1	1	1	0	High	0	1	1	0	7/10
Trigg (2000) [35]	0	1	0	–	0	–	1	1	–	–	3/10
Ensink *et al.* (2002) [12]	1	–	1	0	1	Mod	0	0	1	1	6/10
Tumwine *et al.* (2002) [13]	1	1	1	1	0	High	1	1	0	0	7/10
Hadjer *et al.* (2005) [23]	0	1	1	0	0	–	1	1	0	1	5/10
García and Brown (2009) [33]	1	1	1	0	0	High	1	1	1	–	7/10
Majuru *et al.* (2012) [34]	1	1	1	0	1	High	1	0	0	0	6/10
Subbaraman *et al.* (2013) [21]	1	1	1	1	0	Mod‡	0	0	–	1	7/10

Table 2 (*Continued*)

Authors and year published	Description of methods and limitations: Methodology clearly described	Ownership of water source described	Water use included in a table in results	Explained who was interviewed	Limitations of water quantification discussed?	Rigour of water use measurement methods: Accuracy of water measurement†	Included direct observation	Stratified water use by activity	Explored variations in water use: Captured variation from day to day	Captured variation over seasons	Totals
Oageng & Mmopelwa (2014) [31]	1	1	1	1	0	High	0	0	0	0	5/10
Totals	19/21	12/21	19/21	15/21	8/21	14/21	11/21	10/21	7/21	6/21	

Coding: yes (1), no (0), unclear (–), high, mod, low. Unclear (–) = not mentioned in article (0 points).
*Only measured quantity of water for drinking and cooking. Water for other uses was categorised based on access levels.
†Coding for accuracy of water measurement: high = direct measurement or trained estimation with validation/physical measurement (1 point); mod = trained estimation without validation (1 point); low = self-reporting (0 points).
‡Asked respondents how many times the containers were filled over the course of the previous week.
§Did not visit the same households in each season to explore seasonality (1 point).

use, including but not limited to; bathing, washing, cleaning, rinsing, cooking and if applicable, ablution or domestic agricultural use.

Measurement of water use

To measure various types of water use, different approaches will be necessary. In some cases, water used outside the household will be unquantifiable, for example if bathing or washing is done in a river or a pond. In these cases, all water-related activities should be counted and considered as part of the total water use. These activities may be simply analysed as descriptive statistics (e.g. tallied per person or per household) or proxy values may be used to calculate estimated water use. For ease of comprehension, an example of bathing in a river is used. A researcher would have to identify how much water is used for bathing by other people in the study area that do not bathe directly in the river, and use that average value as a proxy value for river baths. If that is not possible, the researchers will have to consult studies with similar populations and use the amounts of water used per bath recorded in those studies as proxy values.

The most accurate way of quantifying water was through direct measurement, either in litres (e.g. a container of a known size) or by weight. However, this method requires large amounts of resources and is quite invasive for study participants. As it was reported that trained estimation was 'highly accurate' [16] and within one litre (personal communication with Cairncross, March 2, 2015), we recommend that direct measurement by research staff only be used during pre-study data collection and data cross-validation so as to minimise invasiveness.

When the sample size is large, it may be more cost-effective to train data collectors to estimate bucket sizes instead of measuring them directly. This will require rigorous training to ensure that data collectors can uniformly identify the size of all common water carrying containers used in the study setting. Complementary methods may be employed to recall container sizes such as pictures of local water containers of known sizes [19].

Due to the various ways in which water can be collected and used, precision of measurement via questionnaires or observations is unlikely to be 100%, which was exemplified in the studies that discussed limitations of measuring water use. Consequently, it is important that methods be developed to cross-validate water use values. Cross-validation could be done by comparing reported use on a questionnaire to observations done on the same day. Similarly, scales could be used to cross-validate water carried in containers [13]. It will be essential to describe limitations of measuring water use in future studies to better understand ways in which these methods can be improved and/or standardised.

Questionnaires and observations to collect water use measurements

Using questionnaires to interview water collectors was a method employed by nearly all included studies to measure water use. One of the benefits of using self-reporting questionnaires is that they require less time and resources compared to other methods such as observations, or physical measurement by scales or measuring containers. As a result, research fatigue is minimised in the population during cohort studies and/or a larger sample size can be studied, as data collectors will not be required to spend long periods of time to observe each household. One of the shortcomings of using questionnaires is that they are subject to reporting and recall biases.

Only one study was found that discussed water use recall. This study reported that a period of 12 h was the maximum amount of time for accurate recall of water use, yet supporting information was not provided [30]. Twelve-hour recall requires that a subject be visited twice per day to gain insight on a full-day's water use, which would be quite intrusive in a longitudinal study. In this case, a maximum of 24-h recall may be used to collect data on water use but should ideally use findings from the pre-study to triangulate results to account for any underestimation of water use, or at minimum, explicitly state that water use may be underestimated because of a 24-h recall period. Further research on water use recall is warranted, and based on limited evidence [30], recall should be limited to 24 h or fewer until findings are substantiated.

Many of the studies used both questionnaires and observations to measure water use. Observations have their weaknesses as well as strengths. They are resource heavy, requiring both time and manpower; they are also subject to observer bias as well as reactivity, that is possible behaviour change in the study population in response to the observers' presence [40]. On the contrary, recall bias and reporting bias are greatly reduced by direct observations. Research fatigue may be lessened for the participants as there is no requirement for them to maintain a log or diary of water use. In-home observations allow for exploration into certain aspects that may be limited by surveys or source observations. For example, in-home observations would allow for more precise measurement of water use in households that have in-home connections where metering is not an option. It is also perhaps the simplest way to measure water use in households that rely on multiple water sources. In-home observations seemed to be the most accurate option to explore water use per activity and to validate self-reported use. However, Ensink *et al.* [12] reported that purdah traditions (where women are confined to the home) did not allow for in-home observations with male data collectors, highlighting the need for cultural sensitivity to be taken into consideration when planning the study.

Cairncross *et al.* [30] recommend that water use be measured using observations and survey methods. The authors of this article agree but take the recommendation a step further. If data surveys can be designed to estimate water use accurately [16], observations may not be necessary for the entire duration of the study. The authors recommend that observations be used during pre-study research to get a clear picture of overall water use and to cross-validate survey results. Once the surveys are found reliable, observations may be discontinued. However, observations may be used throughout studies if in-depth information on water use is required that is not easily captured in surveys.

Day-to-day and seasonal variability of water use

Differences in day-to-day use were mentioned in most of the articles that visited the households over two or more consecutive days. This is also supported by data in one of the included studies showing that washing clothes accounts for nearly 20% of total household water use [28]. Assuming that washing clothes does not happen every day in all households, this would result in day-to-day variation in water use. Hence, the data suggest it is important to explore day-to-day variation when looking at domestic water use in order to calculate average daily use. This can be achieved through multiple visits on different days of the week. If this is not possible, qualitative exploration of water use on different days of the week may be used, and water use data can be triangulated to account for low and high water use days.

Some inter- and intrastudy variability (2–113 LCPD) can be explained by water access, and some of it can also be explained by how the water use was measured. Seasonal variation was found in four of the six papers [12, 23, 26, 32] that explored seasonal water use, which demonstrates the differences that could arise in surveys that only measure water use or associated indicators during a single point in a year. Seasonal changes in water use may very well have implications of seasonality in hygiene behaviour if water availability is affected [7] or if there is a perception of water limitation [18]. As a result, seasonality needs to be taken into account in future studies on water use whenever possible. Furthermore, these findings in seasonality suggest that baseline studies that explore water use should be repeated at different times of the year to gain a more accurate understanding of the impact of water use. If multiple sampling is not possible, collection of data on water use during different seasons, for example via seasonal mapping, is warranted.

Limitations

It should be noted that we only included studies in this review that clearly described methods used to measure water. This may have affected how many articles we found with significant associations between water access and water use or water use and health and perhaps less publication bias would have been found. Some bias may have been missed due to inadequately described methods in the articles.

Conclusions

In the light of the Sustainable Development Goals' emphasis on water access to improve health [2], establishing a standard definition and standard methodologies to measure the impact of water use is paramount. A number of studies in low-income settings have measured non-metered water use on a household or individual level; however, the articles' quality and outcomes are varied. Because of the various means to collect and use water around the world, a rigid methodology to measure water use is not possible. Based on the findings presented here, the authors offer a number of recommendations to increase the rigour of future studies on water use:

The first step to improved measurements of unmetered water use is defining all components that make up water use and outlining how these components are to be measured. If the goal of measuring water use is to measure its association with health and water is being used outside of the household, then simply measuring water carried into the household is insufficient. Second, a pre-study that involves observations, cultural considerations and direct measurements during water collection periods (these will have to be determined through questioning) should be used to determine optimal methods for obtaining water use information in a survey. The pre-study findings can be used to train data collectors to estimate container volumes, water flow rates, etc. It appears that water use recall period should be no more than 12 h if possible; however, a 24-h period may be acceptable to minimise research fatigue as long as water use underestimation is accounted for. Third, day-to-day variation must be taken into consideration by collecting data on normal days and days of high water use (i.e. washing and bathing days). Fourth, seasonal variation is also important to capture; if funding does not allow for this, qualitative investigation and a seasonal calendar may help shed light on seasonal variations.

These recommendations are in line with the most comprehensive articles which included most of the following methods: stratified water use per activity; calibrated flow rates, for example from pipes or handpumps, when applicable; captured day-to-day and/or seasonal variability in water use; and they discussed limitations of their water use methods. These details, along with clearly described methodologies, should be taken into consideration in future studies that aim to measure water use in unmetered settings.

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