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Drinking water accessibility and quantity in low and middle-income countries: A systematic review

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ABSTRACT

Background: Increasing the quantity of water available for consumption and hygiene is recognized to be among the most efficient interventions to reduce the risk of water-related infectious diseases in low and middle-income countries. Such impacts are often associated with water supply accessibility (e.g. distance or collection time) and used to justify investment in improving access.

Objective: To assess the relationship between the water source location and the quantity of water available in households from low and middle-income countries by identifying the effects of interventions aiming to improve access, and to compare the indicators and measures used to collect information.

Methods: We systematically searched seven databases (i.e. Cairn, Cochrane Library, Embase, MEDLINE, PubMed, Web of Science, Women's Studies International) along with grey literature for articles reporting indicators and measures of accessibility and quantity. We found 6492 records, of which 20 studies were retained that met the review's inclusion criteria.

Results: Most studies were conducted in rural settings and provided suggestive findings to describe an inverse relationship between accessibility and quantity. Overall, a wide range of indicators and measures were used to assess water accessibility and quantity in the selected studies along with their association. The lack of consistency raised concerns regarding comparability and reliability of these methods.

Conclusions: The review findings support the hypothesis that the quantity of water available in households is a function of the source location, but the inconsistency in study outcomes highlights the need to further investigate the strength and effects of the relationship.

1. Introduction

Multiple benefits are associated with improved access to drinking water supply in low and middle-income countries. A positive association between health and access to water supplies has been previously demonstrated (Overbo et al., 2016). Generally, this relationship has shown that increasing the quantity of water available for consumption and hygiene is an efficient intervention to reduce the exposure risk to waterborne (diarrhoeal) diseases, such as gastrointestinal infections (Fry et al., 2010; Mara and Feachem, 1999), and water-washed diseases such as trachoma and scabies (Cairncross and Feachem, 1993; Stelmach and Clasen, 2015). Water accessibility will typically play a role in the amount of water available (i.e. collected or consumed) in households and attributable effects may differ based on the quality and the use of water (Cairncross and Valdmanis, 2006; Overbo et al., 2016).

Having access to water on premises results in a greater quantity and quality of water than when it is located off premises (Brown et al., 2013; Overbo et al., 2016) and is generally associated with positive health outcomes such as the reduction of diarrhoea (Overbo et al., 2016). A lack of access to water on premises means that water must be fetched: women and children, who generally hold the task of fetching water (Graham et al., 2016; Mehretu and Mutambirwa, 1992; Sorenson

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Table 1
General terms used for literature searches.

English	French
water AND (drinking OR hygiene OR domestic) AND (quantity OR quantities OR volume OR liter* OR litre* OR "L" OR gallon*) AND (availab* OR use* OR allocation) AND (access* OR fetch* OR collect* OR distance OR minute* OR meter*)	eau ET (potable OU hygiene OU domestique) ET (quantite OU volume OU litre* OU « L » OU gallon*) ET (disponib* OU utilis* OU allocation) ET (acces* OU collect* OU cherche* OU distance OU minute* OU metre*)

et al., 2011), spend time at the expense of other activities such as education, work (e.g. farming, households, or other), or hygiene practices, and are exposed to different physical health disorders associated with the weight of carrying water (Geere et al., 2010, 2018; Geere and Cortobius, 2017; White et al., 1972).

The burden of fetching water remains widespread where water on premises is not common and is likely to threaten water security. Access to water estimates measured by international bodies such as the WHO and UNICEF now take into account the source location which significantly affects the estimated percentage of the population with access to water (Cassivi et al., 2018; Devi and Bostoen, 2009; WHO/UNICEF, 2017a). In 2015, 29% of the population worldwide did not have access to a safely managed drinking water service: located on premises, available when needed, and free from contamination (WHO/UNICEF, 2017a). In order to improve assessment validity, it is crucial to understand the relationship between water accessibility and the quantity of water available in households.

Published literature, however, yields little insight into the impact of the water source location on the quantity of water available in households. Several studies refer to the "water plateau": a non-linear relationship between the quantity of water collected and the water fetching time and/or distance, based on initial work by White et al. (1972) and a graphic representation found in Cairncross and Feachem (1993). Moving from on premises access to about three to five minutes of collection time, this suggested relationship shows a steep decline in the quantity of water (Howard and Bartram, 2003; UN-Habitat, 2012), after which the amount used plateaus until 30 min where a further decline is then expected. Intervention studies conducted in rural settings in which the distance to the water source was reduced, found that unless the source was moved to the plot, the quantity of water collected did not necessarily increase (Jagals, 2006; Sakisaka et al., 2015). Such results may support the plateau relationship shown by Cairncross and Feachem (1993), but without a systematic analysis, this remains uncertain and unconfirmed especially in urban areas where water collection remains understudied. Furthermore, a 30-min threshold is often used as a proxy to monitor access to water – and has been recognized as such for basic water access in the Sustainable Development Goals (SDG) – although the effect of collection time on water quantity available remains unquantified (Cassivi et al., 2018; WHO/UNICEF, 2017b).

The relationship between accessibility and the quantity of water collected and available for consumption in low and middle-income settings remains as an important literature gap (Geere and Cortobius, 2017; Overbo et al., 2016; Stelmach and Clasen, 2015). A better understanding of this relationship would be valuable to improve the design and evaluation of water related interventions. Possible differences between the impacts of rural and urban source location should be further investigated to ensure equitable access to safe and affordable drinking water for all, as stated in the SDGs.

The overall objective of this systematic review is to assess the relationship between the source location and the quantity of water collected by households in low and middle-income countries. The specific objectives are to identify and compare: a) the effects of interventions applied to improve access; and b) the indicators and measurements used to collect information on water accessibility and quantity.

2. Methods

This review applied the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The research protocol was agreed to by all authors. Study selection was undertaken by two reviewers (AC and SG) and a third reviewer (CD) was consulted in case of any disagreement while screening eligibility.

2.1. Eligibility criteria

Studies reporting the association or the effect of water source location (i.e. its accessibility) on the quantity of water collected and/or available in low and middle-income countries were sought for inclusion in this review. Studies referring to domestic water consumption or use, or those reporting an effect on human health were eligible. Peer-reviewed papers and grey literature published in English, French, Spanish and Portuguese were considered for this review. No restriction related to the publication year or date of coverage was applied for selection.

2.2. Information sources

Seven databases were searched for peer-reviewed literature: Cairn, Cochrane Library, Embase, MEDLINE, PubMed, Web of Science, Women's Studies International. Additionally, grey literature was searched through Google Scholar and governmental websites.

2.3. Search strategy

To ensure study specificity and inclusivity, the selection strategy included different sets of criteria related to water quantity, availability and accessibility (Table 1). The search was conducted with English search terms for all databases except for Cairn which required French.

2.4. Study selection

The selection process was designed following the PRISMA chart flow (Moher et al., 2009). All records identified through databases were downloaded into EndNote X7 reference management software and duplicates were removed before title screening. Titles were screened to determine which studies met the predetermined inclusion and exclusion criteria (Table 2). Titles had to appropriately refer to water for human uses (e.g. drinking, hygiene, domestic) to be selected in the abstract screening. Subsequently, the studies were screened to ensure that the to water source location, a measure for access to water sources, and the quantity of water collected or used, were included. Full text screening was then conducted to determine study eligibility. As a final step, bibliographies of the selected papers were screened to ensure that all relevant studies were included. Grey literature was subject to the same inclusion and exclusion criteria as peer-reviewed research articles.

2.5. Data collection, extraction and analysis

Data extraction was completed using a structured form. The following data were extracted from each selected study: general information (e.g. title, authors, abstract, type of publication, journal, year), study settings (e.g. country objectives, type, site(s) and characteristics, dates, duration), data collection (e.g. study population, sampling, methods, indicators), results (e.g. water source(s), household size, time/distance measurements, trip frequency, person fetching water, quantity measurements, quantity vs time/distance measurements, water use, health indicators if applicable), conclusions and

Table 2
Inclusion and exclusion criteria used for study selection.

	Inclusion	Exclusions
Populations of interest	Human populations, either individual, households or communities.	Animals (e.g. beef, goats) or institutions (e.g. school or health care facilities)
Type of water use	Domestic (e.g. drinking, hygiene).	Harvesting, agriculture, industry, irrigation
Measures included	Water source accessibility (i.e. time (min or h)), distance (m or km) and water quantity (i.e. litres (L) or volume)	Accessibility or quantity is not measured.
Type of measures	Self-reported, direct measurements or observations	
Location	Low and middle-income countries as defined by the World Bank	
Language	English, French, Spanish, Portuguese	

limitations. Underlying data from plots and images included in selected papers were retained and compiled as an additional dataset.

The quality of the selected studies was initially assessed based on the Newcastle-Ottawa Quality Assessment Scale (NOS) for systematic reviews. The original scale from NOS for specific quality criteria for case control, cohort and cross-sectional studies was adapted for this review. The selection of study groups and sampling, methods, and outcomes were the general determinants used for quality assessment. Finally, the general determinants of the selected studies were compared but were not classified in terms of quality. Risk of bias in each study was addressed and compared independently.

The quality of the findings were assessed and compared using descriptive analysis. Structure synthesis of the studies' characteristics and findings was used to perform cross-manuscript analysis. Unfortunately, a lack of comparable, quantitative location and quantity data meant that we were unable to conduct a meta-analysis.

3. Results

3.1. Search results

The intial search yielded 6,488 records with a further two records identified as grey literature (i.e. one discussion paper and one report). After duplicates were excluded, 3,875 records were screened for title eligibility and 223 records were selected for abstract screening, of which 64 were likely relevant. Of the records eligible for full text screening, following the criteria presented in Table 2, 18 were selected for inclusion. The bibliographies of the papers selected through the initial screening process were consulted and two additional records were identified as eligible and included as additional sources. In total, 20 publications were included in the systematic literature review (Fig. 1).

3.2. Study characteristics

A summary of the selected publications is shown in Table 3. Each study was conducted in a single country and in total, 15 different countries were represented. More than three quarters were concentrated in Africa; the remainder took place in Asia (Bangladesh, Sri Lanka) and one in the Americas (Nicaragua). Among these countries, seven are classified as low-, six as lower-middle- and two as upper-middle-income economies (World Bank, 2019). The selected articles were conducted between 1987 and 2017 and were all published in English. Eight of them were conducted with a cross-sectional design, seven used a case-control design, four were conducted as prospective cohorts and one was classified as quasi-experimental. Sampling methods included census, random, purposive, matching and convenience samples. The samples used ranged from 40 to 2,456 participants or households (average n = 861; median n = 490). All studies were exclusively conducted in rural villages or districts except one (Hadjer et al., 2005) that included both urban and rural sites. Twelve reported findings for either a wet or dry season or for both seasons. The others did not specify whether they were conducted in a wet or dry season. No assumption to determine the season was made considering potential variations and changes in the climate throughout the year.

3.3. Water accessibility indicators and measures

Indicators used to measure water supply accessibility were: categorical (i.e. no access, basic access, intermediate, optimal), distance (meters), or time (minutes). Only Hadjer et al. (2005) referred to water service levels and six studies used both time and distance as indicators. The others used network analysis (i.e. shortest path), Euclidian distance (i.e. metres or kilometres), or time (i.e. either one-way or round-trip collection time) from the point of use to the source. Some studies including Mertens et al. (1990); Sandiford et al. (1990) also refer to distance although they used water collection time as an indicator which is consistent with the common use of time as a proxy for distance. Indicators reported in the literature conventionally referred to walking distance or time but this is not always specified. Martinez-Santos (2017) reported that the quantity of water collected per capita was roughly double in households owning a cart, pointing to the importance of transportation resources as a determinant of access and quantity. It is generally assumed that collection time or distance refers to walking but the mode of water transportation during collection (i.e. carrying, carting, cycling, etc.) is often omitted, which may lead to misinterpretation of results.

Studies using both distance and time as indicators for accessibility found similar trends, suggesting that the two indicators could be used interchangeably. After introducing improved water supplies, Peter (2010) and Sakisaka et al. (2015) found a reduction in time and distance, but Martinez-Santos (2017) demonstrated that water consumption was not function of both travel time and distance. Another study found a reduction in collection time but no associated increase in quantity of water consumed (MCC-USA, 2017). In one cross-sectional study, the authors reported using distance rather than time estimates as the reporting of the latter was not reliable because participants were "old and illiterate" (Katsi et al., 2007). None of the studies identified by the review investigated or compared the reliability of self-reported distance and time indicators, used individually or in combination.

Methods used to measure their respective indicators varied among studies: fourteen used self-reported measurements, three used observations (i.e. watching the subject during water collection or at the subject's premises), two used GPS measurements and one used self-reported measurements along with network analysis and routing algorithms. The three studies measured the distance from the point of use to the source directly (Jagals, 2006; Majuru et al., 2012; Martinez-Santos, 2017).

3.4. Water quantity indicators and measures

Two main types of indicators were used to measure water quantity in the selected publications: seven used the quantity of water collected and twelve used the quantity of water consumed. Water collected commonly refers to the quantity of water brought into a household while water consumed reflects the quantity of water used. Although all

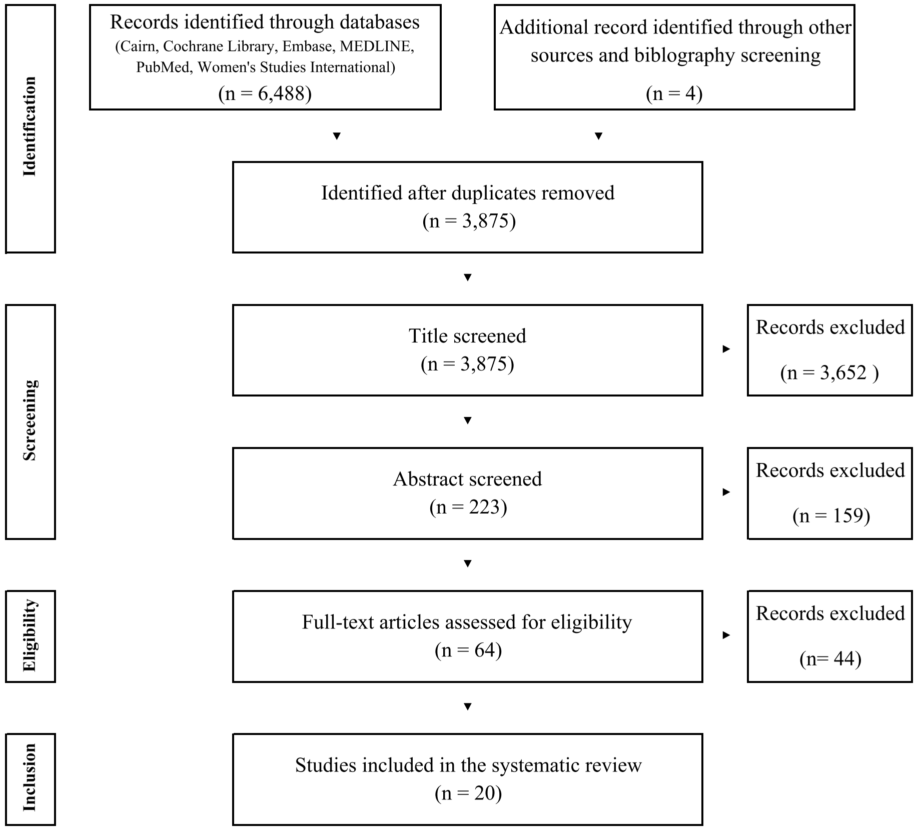

Fig. 1. Flow chart of the selection process.

studies refer to a single indicator, it should be stated that some authors (Hadjer et al., 2005; Katsi et al., 2007; Ketema et al., 2012; Majuru et al., 2012) used different terminologies (e.g. consumed, collected, available, used) which may have implications on the interpretation of reported findings. Indicators were either presented as litres per capita per day (lpcd) or litres per households per day (lphhd). In contrast to all other studies, Gross et al. (2013) used the number of containers collected per day as a proxy for water quantity, where one container carries about 25–35 L.

Self-reported methods were used in the majority of identified studies either alone or in addition to observations. Some studies reported possible limitations attributable to recall bias but such an effect was not assessed. Four studies (Bailey et al., 1991; Cairncross and Cliff, 1987; Hadjer et al., 2005; Jagals, 2006) only used observations to estimate the quantity of water collected or used in households.

3.5. Assessment of the association between accessibility and water quantity

A direct assessment of the association between the two factors of interest was conducted in 11 studies and among those studies, seven found an inverse relationship between the distance and/or time and quantity of water. The remaining studies investigated the association indirectly with the prevalence of trachoma, or independently following improvements to water service (i.e. accessibility and quantity separately). The results from the selected studies generally show an association between water accessibility and water quantity (Table 4). Three quarters of the studies demonstrated evidence or suggestive findings to assess this relationship, among which eight also referred to particular health outcomes (trachoma or diarrhoea-related illness). Five did not find a significant association between water accessibility and quantity.

All of the studies conducted with a prospective cohort design (3) used a direct or independent (i.e. following an improvement) assessment to describe the relationship between water accessibility and quantity. Two studies conducted in the dry season using observational methods concluded that water consumption increased with proximity to a water source. The oldest of the studies included, conducted in Bangladesh (Hoque et al., 1989), used one-way analysis of variance to determine if there were any significant differences between the means of distances and water consumption. A significant decreasing trend ($p < 0.001$) in average water consumption was observed with intervals of increasing distance (i.e. 56 L from 0 to 24 m; 49 L from 25 to 29 m; 42 L from 50 to 99 m; 31 L above 100 m). Using less rigorous indicators than the latter and no statistical tests, the study conducted in Benin (Hadjer et al., 2005) during the dry season described that water consumption was likely to increase with service levels improvement (i.e. 14.6 L/no access; 18.6 L/basic access; 21.2 L/intermediate access). Additionally, another cohort study conducted in Swaziland (Peter, 2010) found that a domestic water project (i.e. improvement) resulted in an increase in the quantity of water collected and used, a reduction in the distance travelled, and a reduction in the time to collect water, but no statistical conclusions were presented. Hadjer et al. (2005); Hoque et al. (1989); Peter (2010) used purposive sampling to recruit participants, which may have increased the risk of selection bias; the generalizability of these findings is unclear.

Two studies analysed the effect of distance improvement on quantity of water. A cross-sectional study conducted in Zimbabwe (Katsi et al., 2007) showed that the quantity of water decreased when self-reported distance increased from near (0 m) to very far (8 km). A quasi-experimental study conducted in South Africa (Majuru et al., 2012) found similar results using a convenience sample. Communities with upgraded water services were travelling shorter distances – physically measured with GPS devices – and consuming more (i.e. an increase in quantity of water). Interestingly, most of the households with enhanced services were reported to pass distance (≤500 m) but fail quantity (15 L per capita per day) benchmarks yet no households failed distance but passed quantity benchmarks. This could suggest that the quantity of

Table 3
Characteristics of included studies.

Reference	Setting		Design					Methods			
								Accessibility		Quantity	
	Country or Region	Season	Type of study	Sampling	Sample (n)	Intervention	Health focused	Indicator	Measurement	Indicator	Measurement
Bailey et al. (1991)	Gambia	Wet	Case control	Total source population	564 children	No	Trachoma	Distance	Self-reported	Collection	Observation
Cairncross and Cliff (1987)	Mozambique	Dry	Cross-sectional	Purposive	667 people	No	Trachoma	Time	Observation	Consumption	Observation
Gross et al. (2013)	Benin	Both	Case control	Phase-in	1838 households	Yes	No	Distance & Time	Self-reported	Containers collected	Self-reported
Hadjer et al. (2005)	Benin	Dry	Prospective cohort	Purposive	40 households	No	No	Access level	Observation	Consumption	Observation
Hoque et al. (1989)	Bangladesh	Dry	Prospective cohort	Purposive	594 households	No	No	Distance	Observation	Consumption	Observations & Self-reported
Jagals (2006)	South Africa	Not reported	Case control	Selective	100 households	Yes	No	Distance	Direct (GPS)	Collection	Observation
Katsi et al. (2007)	Zimbabwe	Not reported	Cross-sectional	Random	140 households	No	No	Distance & Time	Self-reported	Consumption	Self-reported
Ketema et al. (2012)	Ethiopia	Not reported	Cross-sectional	Two-stage random cluster	792 children	No	Trachoma	Time	Self-reported	Consumption	Self-reported
Mahande et al. (2012)	United Rep. Tanzania	Not reported	Case control	Random cluster	96 households	No	Trachoma	Time	Self-reported	Collection	Self-reported
Majuru et al. (2012)	South Africa	Both	Quasi-experimental	Convenient	114 households	Yes	No	Distance	Direct (GPS)	Collection	Observation & Self-reported frequency
Martinez-Santos (2017)	Mali	Dry	Cross-sectional	Semi-random	108 households	No	No	Distance & Time	Self-reported & Direct (network)	Consumption	Self-reported
Mertens et al. (1990)	Sri Lanka	Both	Case control	Random	4439 households	No	No	Time	Self-reported	Consumption	Self-reported & Observation
Nyong and Kanaroglou (1999)	Nigeria	Both	Prospective cohort	Stratified random	250 households	No	No	Distance	Self-reported	Consumption	Self-reported
Oagen and Mmopelwa (2014)	Botswana	Not reported	Cross-sectional	Total source population	60 households	No	No	Distance	Self-reported	Consumption	Direct & Self-reported
Polack et al. (2006)	United Rep. Tanzania	Dry	Cross-sectional	Total source population	416 households	No	Trachoma	Time	Self-reported	Collection	Self-reported
Sakisaka et al. (2015)	Kenya	Not reported	Cross-sectional	Two-stage cluster	1391 mothers	Yes	Diarrhoea	Distance & Time	Self-reported	Consumption	Self-reported
Sandiford et al. (1990)	Nicaragua	Both	Case control	Matching	2456 children	No	Diarrhoea	Distance	Self-reported	Consumption	Self-reported
MCC-USA (2017)	Ghana	Dry	Case control	Matching	1200 households	Yes	No	Distance & Time	Self-reported	Consumption	Self-reported
West et al. (1989)	United Rep. Tanzania	Not reported	Cross-sectional	Random cluster	1908 households	No	Trachoma	Time	Self-reported	Collection	Self-reported

Table 4
Assessment of the association between accessibility (time and/or distance) and quantity of water available.

Reference	Assessment	Variables of interest	Measure of association	Observed association	Statistical significance (95% confidence level)
Bailey et al. (1991)	Direct	Distance/Quantity	Logistic regression	Inverse (r = −0.44)	Significant p = 0.01
Cairncross and Cliff (1987)	Direct	Time/Quantity	Descriptive	Inverse	Not used
Gross et al. (2013)	Independent (Improvement)	Time/Quantity Containers/Quantity	Regression model	Inverse (dry season) Null (rainy season)	Significant Time p < 0.01 Not significant Containers p < 0.1
Hadjer et al. (2005)	Direct	Access level/Quantity	Descriptive	Inverse	Not used
Hoque et al. (1989)	Direct	Distance/Quantity	One-way analysis of variance	Inverse	Significant p < 0.001
Jagals (2006)	Direct	Distance/Quantity	Descriptive	Null	Not significant p-value unknown
Katsi et al. (2007)	Direct	Distance/Quantity	Descriptive	Inverse	Not used
Ketema et al. (2012)	Indirect (Trachoma)	Trachoma/Time Trachoma/Quantity	Multivariate analysis	Positive (time) Inverse (quantity)	Significant p < 0.01
Mahande et al. (2012)	Indirect (Trachoma)	Trachoma/Time Trachoma/Quantity	Univariate analysis	Positive (time) Inverse (quantity)	Significant p < 0.003
Majuru et al. (2012)	Independent (Improvement)	Distance/Quantity	Multilevel linear regression	Inverse	Significant p < 0.001
Martinez-Santos (2017)	Direct	Distance/Quantity Time/Quantity	Single regression model	Null	p-value unknown
Mertens et al. (1990)	Direct	Time/Quantity	Regressions model	Null	Not significant p-value unknown
Nyong & Kanaroglou (1999)	Independent (Seasonality)	Seasonality/Quantity Seasonality/Time	One-way analysis of variance	Inverse	Quantity Significant p < 0.05 Distance p-value unknown
Oagen and Mmopelwa (2014)	Direct	Distance/Quantity	Regression model	Null	Not significant p = 0.413
Peter (2010)	Independent (Improvement)	Time/Quantity	Difference	Inverse	Not used
Polack et al. (2006)	Direct	Time/Quantity	Linear regression	Inverse (r = −0.08)	Significant p < 0.05
Sakisaka et al. (2015)	Independent (Improvement)	Distance/Quantity Time/Quantity	*t*-test	Inverse	Absolute change Significant p < 0.006
Sandiford et al. (1990)	Direct	Distance/Quantity	Multiple regression model	Inverse (Coef. −0.04)	Significant p < 0.05
MCC-USA (2017)	Independent (Improvement)	Time/Quantity Distance/Quantity	Difference	Positive (time: quantity) Null (distance:quantity)	Significant p-value unknown
West et al. (1989)	Indirect (Trachoma)	Trachoma/Time Trachoma/Quantity	Regression analysis	Positive (time) Null (quantity)	Significant Time p < 0.001 Not significant Quantity p < 0.2

water available is likely to increase following distance improvements but not the other way around.

Eight studies focusing on health outcomes also described an association between water accessibility and quantity. Using multivariate, univariate, or regression analysis, Ketema et al. (2012); Mahande et al. (2012); West et al. (1989) assessed the association between the prevalence of trachoma and water quantity in Tanzania and Ethiopia,. The authors determined that the risk of trachoma significantly increases with increasing collection time and (in two studies) with a decreasing quantity of water used.

Three additional studies (Bailey et al., 1991; Cairncross and Cliff, 1987; Polack et al., 2006) focusing on trachoma examined a direct association between accessibility and quantity. Findings are consistent as they reveal an inverse relationship between poor water accessibility (i.e. distance and/or time) and quantity. Bailey et al. (1991) and Polack et al. (2006) considered the whole population in the communities studied which reduces the risk of missing potential insight and increases reliability.

Two further studies focusing on diarrhoea as a determinant of either health or well-being also showed similar patterns or association between accessibility and quantity. One study that used absolute change in the percentage of the population to assess the improvement following the introduction of tube wells in rural Kenya found that the new wells significantly reduced the distance from 500 to 300 m, the time from 30 to 15 min and increased the quantity of water consumed per households from 82.6 L to 99 L (Sakisaka et al., 2015). The authors did not report whether they observed a direct association between quantity and accessibility, but this was not the aim of the study. The other study investigated diarrhoea and water availability behaviours in rural Nicaragua (Sandiford et al., 1990) using regression modelling to assess the relationship between per capita water consumed and distance from the source. Results show that water consumption varies little when the source is located within 18 m but that the quantity drops from approximately 30 L–20 L as the distance increases to 180 m. No significant change was observed between 180 m and 560 m but a reduction in quantity was observed again after 560 m. No significant variations in water consumption were reported between rainy and dry seasons in selected households.

Two additional studies (Gross et al., 2013; Nyong and Kanaroglou, 1999) examined and compared water accessibility and quantity variations with regard to seasonality. Nyong and Kanaroglou (1999) followed a cohort in Northeastern Nigeria and found that more households were travelling a greater distance during the dry season while the quantity collected increased during the rainy season ($p < 0.05$). The association between accessibility and quantity variables was not directly assessed. Gross et al. (2013) found a similar result in a case-control study conducted in Benin during both rainy and dry seasons. The authors used regression models to compare the treatment effect of upgrading water services and reported a reduction of 19 min in terms of round-trip collection time ($p < 0.01$) and an increase of 30% in containers collected per day in the dry season ($p < 0.1$). No significant evidence for an effect was found during the rainy season as most households used rainwater collected on their premises, suggesting a reduced collection time.

In contrast, five publications (Jagals, 2006; Martinez-Santos, 2017; MCC-USA, 2017; Mertens et al., 1990; Oageng and Mmopelwa, 2014) reported no significant association between water accessibility and quantity. A case-control study (Jagals, 2006) conducted in rural South Africa used descriptive analysis to determine the effect of improving water supply services in the community (i.e. from surface water to tap water). Although the average distance was reduced from 750 to 120 m, no significant increase in water quantity was observed. Results from a similar study (MCC-USA, 2017) conducted in Ghana suggested that the water supply interventions reduced the time to collect water by 3 min round-trip, but did not significantly reduce the distance nor increase the quantity of water consumed. The authors noted that discrepancy between time and distance could have been attributable to the perceived time improvement. In a case-control study conducted in Sri Lanka (Mertens et al., 1990), regression models demonstrated that the average water consumption (above 25 lpcd) did not correlate with the time to collect water in households without piped water supplies (90% of households had access within 1 km) although quantity was observed to decrease with increasing time. Regression results from a cross-sectional study in Botswana are similar (Oageng and Mmopelwa, 2014): no significant relationship between water consumption (ranging between 0 and 40 lpcd; average 20.6 lpcd) and distance to the water source was observed. With an average distance of 559 m, the longest distance to the water source was 1.5 km. Although the sample includes the total source population, it only refers to one village which mainly relied on the local river as its primary water source. Similarly, a cross-sectional study using regression models did not find a relationship between water consumption (ranging between 1.3 L and 25.7 L; average 7.3 L) and self-reported time to collect water (ranging between 3.4 and 74.9 min; average 20.3 min) nor direct network distance to the water source (ranges between 51 m and 4702 m; average 1017 m) (Martinez-Santos, 2017). Authors reported that most households had access to their own excavated well, which may have had an effect on the null assumption.

3.6. Other factors and effects

Six studies were conducted following an intervention to upgrade water service in rural communities (Gross et al., 2013; Jagals, 2006; Majuru et al., 2012; MCC-USA, 2017; Peter, 2010; Sakisaka et al., 2015) and either took place before and/or after the intervention or referred to served cases and unserved controls, i.e. communal water supply was improved from surface water or other unimproved sources. The distance or time to collect water was said to be improved in all of these studies, although the quantity of water collected or consumed was not significantly increased in two studies (Jagals, 2006; MCC-USA, 2017). Gross et al. (2013) also reported that time savings from water supply improvements led to a trade-off for water quantity as the number of water containers collected per day increased. Authors suggested that the number of households using two sources increased after the improvement, meaning that households also continued using their previous unimproved sources. This is consistent with findings from Peter (2010); Sakisaka et al. (2015) who investigated the effect of an intervention on water access.

Further studies demonstrated that the quantity of water available varied between households using multiple and alternatives sources of water. Alternative water sources located closer to the households were used in addition to sources from which drinking water was collected. The use of separate sources for drinking water and other purposes increase the quantity available for hygiene behaviours and reduce the risk or prevalence of trachoma (Katsi et al., 2007; Mahande et al., 2012; Martinez-Santos, 2017; Mertens et al., 1990).

Water for hygiene was further predicted by the time required to collect water and the quantity of water available in households (Polack et al., 2006). Nyong and Kanaroglou (1999) suggested that cleaning activities would first be given up in a context of water scarcity. Likewise, given an increase in the quantity of water in rural Mozambique, 70% of it was devoted to bathing and washing activities (Cairncross and Cliff, 1987). It was reported that the interventions to improve access led to an increase in water quantity used for personal and domestic hygiene (e.g. hands washing, bathing, washing dishes and clothes) which would likely be attributed to the use of alternative sources as a supplement for such purposes (Peter, 2010; Sakisaka et al., 2015).

Likewise, results show that the type of source used by households may have an impact on water availability. In Nicaragua (Sandiford et al., 1990), the mean water consumption per capita was 27.7 L for protected wells compared to 18.2 L for unimproved water sources. Mertens et al. (1990), however, found that the type of source used by households wasn't related to the quantity of water available for consumption. In contrast, households in Nigeria would rather use sources of water with lower perceived quality located closer than to travel farther to fetch water from a source with a better perceived quality (Nyong and Kanaroglou, 1999). No significant difference between the quantity of water consumed was found between the dry and wet seasons suggesting that the same sources were used throughout the year.

Finally, the potential effect of household size on water accessibility and/or quantity was investigated in six studies. Hadjer et al. (2005); Hoque et al. (1989); Katsi et al. (2007) and Sandiford et al. (1990) found an inverse association between the number of household members and the quantity of water collected or consumed per capita. The larger the household size, the lower the collected or consumed water quantity per person. Bailey et al. (1991); Gross et al. (2013) did not, however, find an association between household size and either the amount of water available or the time to collect water. With respect to community size, water sources serving fewer people were more likely to be located closer to users' households and this proximity was considered as a determinant of households' water consumption in Bangladesh (Hoque et al., 1989).

4. Discussion

4.1. Association between accessibility and quality

This systematic literature review identified eleven studies that investigated, using direct assessment, the association between water accessibility and quantity: seven found an inverse correlation between distance or time from the water source and water quantity at the household and four reported no association. Among studies reporting a correlation, only four used statistical tests to assess the magnitude of the effect, and all of those publications found a significant association ($p < 0.05$) (Bailey et al., 1991; Hoque et al., 1989; Polack et al., 2006; Sandiford et al., 1990). The lack of precise accessibility measures in several of the studies and incomparable metrics for accessibility or quantity of water limits the authors' ability to clearly illustrate the relationship or confirm the effect of the water plateau suggested by Cairncross and Feachem (1993). Studies reporting no association between water accessibility and quantity (Jagals, 2006; Martinez-Santos, 2017; MCC-USA, 2017; Mertens et al., 1990; Oageng and Mmopelwa, 2014) were conducted in settings where the lack of association appears to be explicable: most recruited households reported having access to water within a short distance (e.g. the longest distance being 1.5 km with 90% of households having access within 1 km), gained a marginal improvement in terms of collection time (e.g. reduction of 3 min round-trip) or were using alternative sources (e.g. their own excavated well). This would likely suggest that the extent of the relationship is reduced when a source is located within 30 min round-trip or 1 km as the widely recognized threshold for access (Howard and Bartram, 2003; WELL., 1998; WHO/UNICEF, 2017a). Generally then, the extent of the relationship between accessibility and quantity is context dependent and varies according to factors including proximity, density (i.e. source and population) and overall household water supply (i.e. multiple sources).

Evidence indicates that increases in water accessibility (by reducing the distance) result in shorter collection times, the latter being also correlated with an increase in water quantity collected or consumed by households. None of the studies included in this review quantified the relationship between collected and consumed quantity as they either examined water availability or water used (i.e. collected or consumed). The results, however, suggest a possible confounding or modification effect, which would require further investigation, as collection time is often reported as a proxy either for distance or for water quantity (Alhassan and Kwakwa, 2014; Cairncross and Feachem, 1993; Devi and Bostoen, 2009; Evans et al., 2013). Very few general studies have investigated the effect and the interactions between accessibility and water quantity. This review supports the need for further research.

4.2. Indicators and measures

Findings from this review do not allow us to state whether specific indicators for accessibility or quantity are more appropriate than the others. Some authors suggest that distance is a better proxy for access than quantity (Sandiford et al., 1990) or that self-reported time is not an appropriate proxy for distance (Ho et al., 2014), while others recommend the use of either (Nygren et al., 2016) or both (Gross et al., 2013) time and distance indicators to measure water accessibility. The type of water source and the time needed to collect are commonly used as proxy indicators for water accessibility. Their widespread use is mainly attributable to the convenience of self-reported measurements and lack of direct measures in national household surveys (e.g. MICS, DHS, LSMS) often used as main sources of information to measure progress. Important variables required for a nuanced understanding of accessibility such as water quantity and trip frequency as well as other factors (e.g. seasonality, secondary/alternative sources and post-collection contamination) are rarely included in national surveys. This lack of data limits the comprehensive analysis of water accessibility through such surveys and quantity issues especially where water fetching is widespread.

Two thirds of the studies included in the review used self-reported measurements for both accessibility and quantity measures. None of the publications included parallel measures to compare the reliability of self-reported measurements although the latter are subject to recall bias (Bartram et al., 2014; Ramesh et al., 2015). Methods such as GPS-based distance calculations, observations and direct measurements need to be explored further for water accessibility research and interventions as they may reduce such bias and increase data reliability (Crow et al., 2013; Jimènez and Pèrez-Foguet, 2008; Ntozini et al., 2015; Pearson, 2016; Tamason et al., 2016). Exploring and comparing the reliability of alternatives to self-reported methods are necessary to strengthen national and international monitoring and improve our understanding of water supply accessibility. Improved measurements will be valuable in efforts to reduce the burden of fetching water and prevent water-related infectious diseases associated to lack of access.

4.3. Health outcomes

Although health outcomes were not a factor for study selection, it should be noted that eight studies selected in the review focused primarily on water-related diseases (i.e. diarrhoea and trachoma). Further to health outcomes, most studies found an inverse association between water quantity and poor accessibility which suggest the importance of both factors. Findings regarding trachoma are consistent: risk or prevalence increases along with time or distance. (Bailey et al., 1991; Ketema et al., 2012; Mahande et al., 2012; Polack et al., 2006). Only one study did not find an association between the quantity of water and the risk of trachoma (West et al., 1989). Studies that relate to diarrhoea found mixed results: diarrhoea was associated with collection time (Polack et al., 2006) but did not relate to the quantity of water available in households (Sakisaka et al., 2015; Sandiford et al., 1990). The reason that intervention are not uniformly effective in reducing diarrhoea might additionally be explained by high concentrations of faecal contamination in water available for consumption (Wolf et al., 2018). This could be related to the quality of water collected or storage practises which are likely related to water source accessibility. It seems likely that houseolds are willing to use unsafe water sources located closer to the house rather than walking further for good quality water (Nyong and Kanaroglou, 1999; Smiley, 2017). Of further consideration would be how the distance or time to fetch water would affect both the quality and quantity of water collected by households. This is consistent with findings from previous studies suggesting the reduction of fetching distance and time to ensure adequate volume for use and improve populations' health (Howard and Bartram, 2003; Pickering and Davis, 2012).

4.4. Seasonality and settlement type

Ensuring access to sufficient quantities of safe water for improving health is widely recognized as a fundamental intervention to reduce poverty, improve resilience, and support economic development. Yet, population growth, urbanization and emerging threats associated with climate change intensify the challenges linked to water access, particularly in low resource contexts with limited coping strategies (Fulco 2009; Meyiwa et al. 2014; de Lira Azevêdo et al., 2017).

Although variations in water access may be attributable to seasonality, several studies included in this review did not specify whether data had been collected in a dry or wet season (Jagals, 2006; Katsi et al., 2007; Ketema et al., 2012; Mahande et al., 2012; Oageng and Mmopelwa, 2014; Peter, 2010; Sakisaka et al., 2015; West et al., 1989). Previous studies raised concerns about the impact of seasonality on water access, i.e. the quantity of water was likely to decrease along with increased distance in drought periods and that microbial water quality was subject to considerable deterioration in the wet season (Curtis, 1986; Kulinkina et al., 2016; Kumpel et al., 2017; Mason, 2015). This is consistent with findings reported in studies investigating water access in both dry and wet seasons (Gross et al., 2013; Mertens et al., 1990; Nyong and Kanaroglou, 1999). It is essential to study the impact of seasonality on access to water further, as suggested in the literature (Brown et al., 2013; Hadjer et al., 2005; Ho et al., 2014; Ntozini et al., 2015; Tamason et al., 2016; Yu et al., 2017). More importantly, seasonal variations should be examined to determine whether indicators and methods used in national household surveys – which currently not specify any particular season - and other studies should reflect such variability. Trends and estimations used to monitor and report progress in terms of access may be particularly vulnerable to seasonal bias considering that most studies are conducted in the dry season for practical reasons (Wright et al., 2012), which strengthens concerns regarding the reliability of such findings. Further evidence is required to determine the effect of seasonality and its strength on global estimations. Almost all studies were conducted in rural settings and do not refer to any urban settings. Although it is recognized that access to water is more problematic in rural settings, universal access to piped water supply is generally not actively expanded in urban, peri-urban or informal settings (Adams and Smiley, 2018; Bain et al., 2014; Dos Santos et al., 2017). Rapid urbanization necessarily requires improvements in urban services, but will aalso exacerbate inequities between urban and rural populations (Bain et al., 2014; Wolf et al., 2013). The relationship between accessibility and quantity is underexplored in urban and peri-urban areas and would require further investigation to understand context-specific differences and determine where efforts are still needed. Also of interest are the contextual and situational characteristics of the study sites selected. Aside from the actual distance between the water source and the point of use, the effect of environmental components or topography (i.e. type of soil, terrain gradient, land use, etc.) and individual choices or behaviours (i.e. walking speed, containers used) may increase the difficulty of fetching water in terms of time and physical effort. This could have an impact on water accessibility and quantity of water collected (White et al., 1972), which was not considered in any study included in this review.

5. Limitations

This systematic review was conducted using a comprehensive search strategy along with specific inclusion criteria and general limitations may include study selection. Although there were no results from database searches in any language other than English, French, Spanish or Portuguese, it is possible that a relevant study published in another language was not found. Additionally, only studies conducted in low and middle-income countries were selected for this review considering the widespread burden of fetching water in these regions. This systematic review includes papers published prior to the completion of the selection (i.e. February 2018) which implies that any additional relevant studies published after this date would not have been captured. Although studies were compared despite the inconsistency in methods, no aggregated results were presented to limit misleading conclusions. Information synthesized and summarized in this review is subject to author's interpretation and may not reflect evidence beyond its scope.

6. Conclusions

Interactions and linkages between accessibility and quantity remain unclear. This systematic review highlights the importance of using appropriate and comprehensive indicators and methods to monitor access and evaluate water supply interventions. Findings suggest that the quantity of water available in households is likely a function of time or distance required to collect water in rural settings. The strength of the relationship could not be determined from the review and remains an important knowledge gap which should be assessed through an evidence-based approach and later investigated with the use of statistical techniques such as meta-analysis. Additional work is necessary to characterize and increase water security and seasonal reliability, reduce the burden of fetching water and prevent water-related infectious diseases. Future findings will be essential to ensure suitable water-related interventions and appropriate responses to needs. It is a timely exercise to reach universal and equitable access to safe and affordable drinking water for all by 2030 as set in Target 6 of the Sustainable Development Goals (SDG).Acknowledgements

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Conflicts of interest

Authors have no actual or potential conflict of interest to declare regarding this research.

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