Access to drinking water in low-and middle-income countries:
Monitoring and assessment

by

Alexandra Cassivi
B.Sc., Université Laval, 2015
M.A., Université Laval, 2017

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We acknowledge with respect the Lekwungen peoples on whose traditional territory the university stands and the Songhees, Esquimalt and WSÁNEĆ peoples whose historical relationships with the land continue to this day.

Supervisory Committee

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Abstract

Lack of access to drinking water remains widespread as 2.1 billion people live without safely managed service that includes improved water sources located on premises, available when needed, and free from contamination. Monitoring global access to drinking water is complex, yet essential, particularly in settings where households need to fetch water to meet their basic needs, as multiple factors that relate to accessibility, quantity and quality ought to be considered. The overall objective of this observational study is to increase knowledge surrounding monitoring and assessment of access to drinking water supply in low-and middle-income countries. The dissertation was comprised of five manuscripts which address the objective using various approaches including systematic review (manuscript 1), secondary data analysis (manuscript 2), and primary data analysis (manuscripts 3-5) to gather evidence towards improving access to drinking water. Primary data were collected through a seasonal cohort study conducted in Southern Malawi that included 375 households randomly selected in three different urban and rural sites. Methods used included structured questionnaires, observations, GPS-based measurements, and water quality testing. Findings from this study highlight the importance of conducting appropriate assessment of household behaviours in accessing drinking water in view of improving reliability of the indicators and methods used to monitor access to water. Seasonal variations that may affect water sources' reliability and household's needs should be put forward to improve benefits of improving access to water and sustainable health outcomes. Further to target reliable and continuous availability from an improved water source at proximity to the household, interventions should aim to ensure safe quality of water at the point of use for mitigating the effect of post-collection contamination, and ensure sufficient quantities of water to allocate for personal and domestic hygiene. Focusing on the benefits of improving access to water at the point of consumption is essential to generate more realistic estimations, suitable interventions and appropriate responses to need.

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List of Abbreviations

DHS	Demographic and Health Surveys
GDP	Gross Domestic Product
IO	International Organization
JMP	Joint Monitoring Programme for Water Supply, Sanitation and Hygiene
LMIC	Low and Middle-Income Countries
MDG	Millennium Development Goals
MICS	Multiple Indicator Cluster Surveys
NCRSH	Malawi National Committee on Research in the Social Sciences and Humanities
NGO	Non-Governmental Organization
OD/ODF	Open Defecation/Open Defecation Free
ODA	Official Development Assistance
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SDG	Sustainable Development Goals
UN	United Nations
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
WHO	World Health Organization

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Introduction

Background

Access to drinking water is indispensable for human life and has been recognized as such in 2010 by the United Nations Assembly through the Human Right to Water and Sanitation (UN Committee on Economic Social and Cultural Rights 2010). Lack of access, however, remains a global issue as 2.1 billion people live without access to water on their premises among which hundreds of millions of people live without at least an improved water source, that is adequately protected from outside contamination, within close proximity (WHO/UNICEF 2017a). Securing access to sufficient quantities of safe drinking water is fundamental to reduce prevalence of water-and excreta-related diseases, improve global health and vulnerability to poverty (Howard and Bartram 2003). This is critical in view of population growth, urbanization and emerging threats associated to climate change that will likely intensify challenges associated to water access, particularly in low resource contexts (de Lira Azevêdo et al. 2017, Fulco 2009, Meyiwa et al. 2014).

In settings without piped water supply, the burden of fetching water remains widespread particularly for women who are typically responsible for management of a household's water supply (Geere et al. 2010, Graham et al. 2016). Water sources proximity and reliability will likely influence quantity and quality of water collected and used by households. Limited access to safe drinking water increases concerns related to water-and excreta-related diseases (Mara and Feachem 1999). Whereas contaminated water increases prevalence of waterborne diseases through ingestion and exposition (e.g., consumption, food contamination), limited access may further curtail availability for personal and domestic hygiene increasing incidence of water-washed diseases (Howard and Bartram 2003). Health implications are further attributable to post-collection contamination of water that can occur at different stages from the point of collection to the point of consumption, and this relates to households behaviours in accessing water (Churchill 1987, Wright et al. 2004b).

Water quality and quantity relate to health, but the role of the proximity to different sources on those measures is not fully characterized. Published literature yields few insights for the impact of the location of primary and alternative water sources on the quantity and quality of water collected and used in households without access to water on their premises. Interactions and linkages between the location of the water source, the quantity and the quality of water collected, stored and used within households along with their associated health impacts remains inadequately addressed in the literature.

Further evidence is needed taking into consideration factors such as household preferences and behaviours in choosing and accessing water source in view of seasonality and reliability variations. This must be assessed through an evidence-based approach to better understand the impact of water supply interventions on health and to provide a more effective design of water supply systems.

Motivations

A target of universal and equitable access to safe and affordable drinking water for all by 2030 was established by the Sustainable Development Goals (SDGs) of the United Nations (WHO/UNICEF 2017a). This builds on the previous target to halve by 2015 the proportion of people without sustainable access to safe drinking water for the Millennium Development Goals. The indicator used to measure progress towards SDG target 6.1 is the proportion of the population using safely managed drinking water service, which refers to the use of an improved water source that is located on premises, available when needed, and free from contamination (WHO/UNICEF 2017b). In 2015, 42.5% of the worldwide population was, however, left behind without access to water on their premises, and this calls for further consideration. Understanding the burden of fetching water is necessary to characterise how access to drinking water can be improved in settings without access to water on their premises. Different factors that relate to water accessibility, quality and quantity along with households' preference and behaviours, and environmental effects should be explored towards a multifaceted definition of access.

A lack of precise information to monitor access to drinking water is mainly attributable to data limitations in national household surveys (e.g. MICS, DHS, LSMS), a main source of information for global estimates. As a result, the type of water sources and the self-reported time needed to collect water are commonly used as a proxy indicator of water accessibility to measure coverage of access. The measurement of quality is challenging in national household surveys and SDG monitoring, but quality testing modules are becoming more commonly available which likely set the tone for the future implementation (Cronin et al. 2017, WHO/UNICEF 2017a). Multiple variables such as water quantity and trip frequency remains mostly unavailable in national surveys. Other factors such as seasonality, alternative sources and post-collection contamination are often limiting by their complexity. The omission of factors of access, however, constrains comprehensive analysis of access to water where water fetching is an issue and led to a gross overestimation of the population with reasonable access to drinking water (Cassivi et al. 2018a, Cassivi et al. 2017b, Devi and Bostoen 2009).

Exploring access to water, using various methods, will contribute to strengthening global estimations and improving our understanding of water supply. This is also essential to ensure suitable water related interventions and appropriate responses to needs. Overall, this will be valuable in efforts to characterise and increase water security and equity, reduce the burden of fetching water and prevent water-related infectious diseases associated to lack of access. This is a timely exercise to reach universal and equitable access to safe and affordable drinking water for all by 2030 as set in the target 6 of the Sustainable Development Goals (SDG) (WHO/UNICEF 2017a).

Contributions

This dissertation is comprised of five manuscripts that support the overall objective of this research which is to increase knowledge surrounding access to drinking water supply in low-and middle-income countries. This was done through looking at it with a monitoring and assessment perspective.

The first manuscript (Chapter 1) is a systematic review exploring the relationship between water accessibility and water quantity, which represent important grounding for the elaboration of this research project. The second manuscript (Chapter 2) include secondary data analysis conducted using available national household surveys to describe emerging trends on progress and inequalities in water supply and sanitation services over a 25-year period in Malawi. Evaluating the extent of available data sources in the study area allowed to develop the methodological approach used for primary data collection.

The prospective cohort study was conducted in three sites of different population density in Southern Malawi. The first two sites were informal settlements located in peri-urban Blantyre (i.e., Ndirande, Mbayani) and the last site was composed of four different rural villages located in Chikwawa District (i.e., Kadzumba, Frank, Bereu and Chambuluk). The study comprises two visits in selected households: 1) baseline data collected during the rainy season (April 2019); 2) follow-up data collected during the dry season (September 2019).

The third manuscript (Chapter 3) contains results obtained from baseline data and aimed to appraise the reliability of self-reported measurements and alternatives to monitor access to drinking water in view of promoting appropriate and easily replicated approaches to generate global estimates.

The fourth manuscript (Chapter 4) comprised data on water quality and post collection contamination collected during both rainy and dry season, and aimed to improve understanding of households' behaviours in collecting water to further identify critical points of contamination.

The fifth manuscript (Chapter 5) evaluates seasonal variations with regard to households' preferences and alternatives in accessing multiple water sources and allowed to assess the impact on water accessibility, quantity and quality and their interlinkage.

The five manuscripts were submitted or are intended to be submitted to journals, and were all written as lead author. The author contributions and state of the publication of each manuscript are described on the title page of each chapter.

Chapter 1

Manuscript Title:

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

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Author contributions:

AC lead the systematic review under CD, ET and EOW supervision. RB contributed to the design and conceptualize of the methods. 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. AC conducted data analysis. All authors revised and commented the manuscript, prepared by AC.

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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 searched seven databases along with grey literature and found 6492 records, including 20 studies that met the review's inclusion criteria. 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 selected studies. A lack of consistency raised concerns regarding comparability and reliability of these methods.

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

Keywords

Water supply | Drinking water | Accessibility | Quantity | Hygiene | Health

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 diseases, such as gastrointestinal (diarrheal) 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 diarrhea (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 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. 2018, Geere and Cortobius 2017, Geere et al. 2010, 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. 2018b, 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 minutes 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-minute 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. 2018b, 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 settings. 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.

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.

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.

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.

Search Strategy

To ensure study specificity and inclusivity, the selection strategy included different sets of criteria related to water quantity, availability and accessibility (Table 1.1). The search was conducted with English search terms for all databases except for Cairn which required French.

Table 1.1. 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*)

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 1.2). 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.

Table 1.2. 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	

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 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.

Results

Search Results

The initial 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 1.2 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 (Figure 1.1).

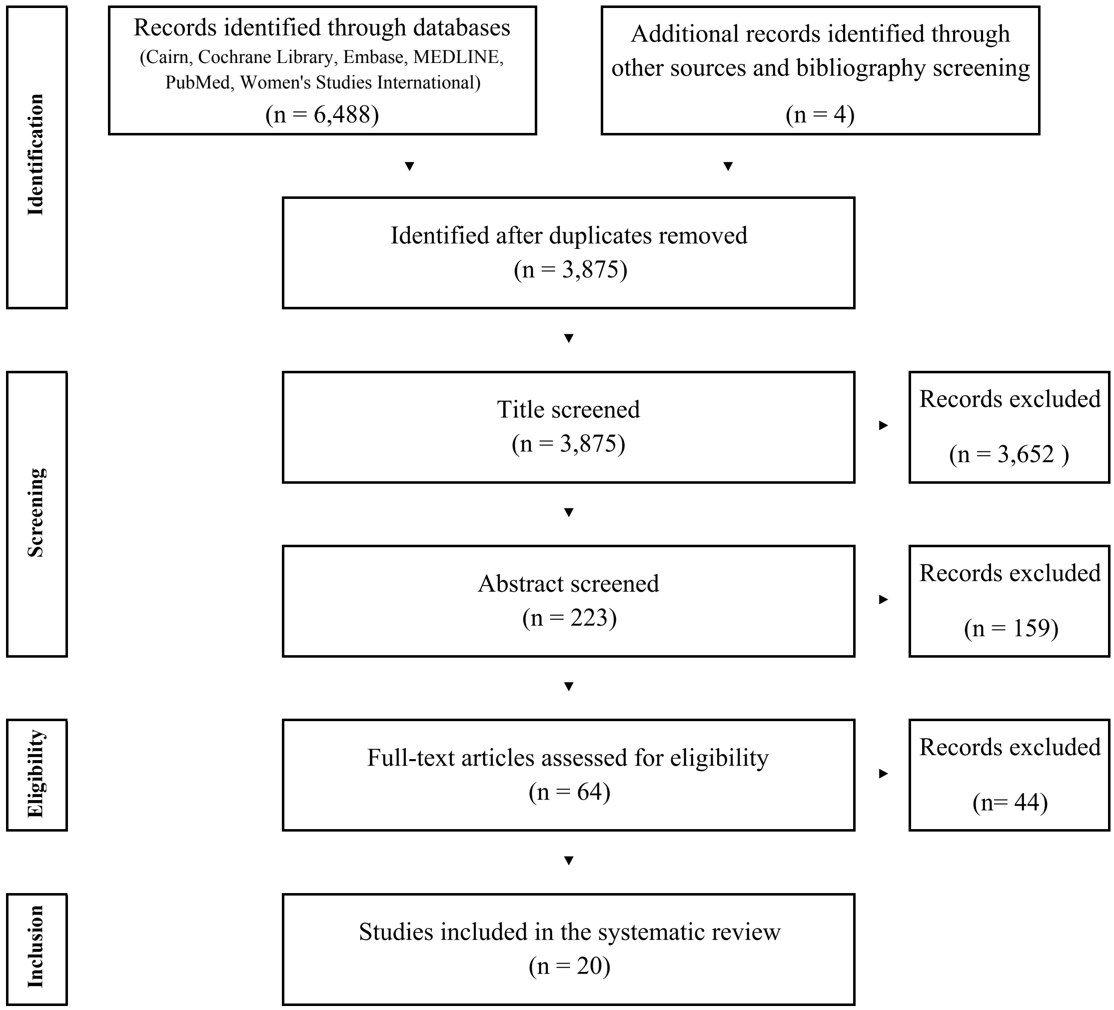

Figure 1.1. Flow chart of the selection process.

Study Characteristics

A summary of the selected publications is shown in Table 1.3. 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 (*M* = 861; *Mdn* 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.

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).

Table 1.3. Characteristics of included studies.

	Setting		Design					Methods			
								Accessibility		Quantity	
Reference	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 & 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 and 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

Table 1.3. *Cont.*

	Setting		Design					Methods			
								Accessibility		Quantity	
Reference	Country or Region	Season	Type of study	Sampling	Sample (n)	Intervention	Health focused	Indicator	Measurement	Indicator	Measurement
Mertens *et al.* (1990)	Sri Lanka	Both	Case control	Random	4439 households	No	No	Time	Self-reported	Consumption	Self-reported & Observation
Nyong & Kanaroglou (1999)	Nigeria	Both	Prospective cohort	Stratified random	250 households	No	No	Distance	Self-reported	Consumption	Self-reported
Oagen & Mmopelwa (2014)	Botswana	Not reported	Cross-sectional	Total source population	60 households	No	No	Distance	Self-reported	Consumption	Direct & Self-reported
Polack *et al.* (2005)	United Rep. Tanzania	Dry	Cross-sectional	Total source population	416 households	No	Trachoma	Time	Self-reported	Collection	Self-reported
Sakisaka *et al.* (2014)	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
US Millennium Challenge Co. (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

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 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 litres.

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.

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 1.4). 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.

Table 1.4. 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 & 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 & Mmopelwa (2014)	Direct	Distance/Quantity	Regression model	Null	Not significant $p = 0.413$

Table 1.4. *Cont.*

Reference	Assessment	Variables of interest	Measure of association	Observed association	Statistical significance (95% confidence level)
Peter (2010)	Independent (Improvement)	Time/Quantity	Difference	Inverse	Not used
Polack *et al.* (2005)	Direct	Time/Quantity	Linear regression	Inverse ($r = -0.08$)	Significant $p < 0.05$
Sakisaka *et al.* (2014)	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 $p < 0.05$
US Millennium Challenge Co. (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 $p < 0.2$

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 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 minutes 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 metres but that the quantity drops from approximately 30 L to 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 minutes 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 minutes 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 minutes; average 20.3 minutes) 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.

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).

Discussion

Association between Accessibility and Quantity

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 minutes 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 minute round-trip or 1 kilometre 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.

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.

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).

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) (Fulco 2009, Meyiwa et al. 2014).

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. 2016b, 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. 2014b, 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. 2014b, 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.

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.

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).

Chapter 2

Manuscript Title:

Trends in access to water and sanitation in Malawi: Progress and inequalities (1992-2017)

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AC lead conceptualization, design and implementation of the analysis with the supervision of CD, ET, and EOW. AC analyzed the results and wrote the manuscript. All authors commented and contributed to the final version of this manuscript.

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Abstract

Billions of people globally gained access to improved drinking water sources and sanitation in the last decades, following efforts towards the Millennium Development Goals. Global progress remains a general indicator as it is unclear if access is equitable across groups of the population. As Agenda 2030 called for "leaving no one behind", there is a need to focus on the variations of access in different groups of the population, especially in the context of the least developed countries including Malawi. We analyzed data from the Demographic Health Survey (DHS) and the Multiple Indicator Cluster Survey (MICS) to describe emerging trends on progress and inequalities in water supply and sanitation services over a 25-year period (1992 - 2017) and to identify the most vulnerable population(s) in Malawi. Data were disaggregated with geographic and socio-economic characteristics including regions, urban and rural areas, wealth and education levels. Analysis of available data revealed progress in access to water and sanitation among all groups of the population. The largest progress is generally observed in the groups that were further behind at the baseline year, which likely reflects good targeting in interventions/improvements to reduce the gap in the population. Overall, results demonstrated that some segments of the population - foremost the poorest Southern rural populations - still have limited access to water and are forced to practise open defecation. Finally, we suggest including standardized indicators that address safely managed drinking water and sanitation services in future surveys and studies to increase accuracy of national estimates.

Keywords

Sustainable Development Goals (SDGs) | Drinking water | Open defecation | Environmental Health | Malawi

Introduction

Access to safe water and basic sanitation is indispensable for human life and dignity and has been recognized as such through the Human Right to Water and Sanitation (UN Committee on Economic Social and Cultural Rights 2010). Efforts to improve access were accelerated as a result of with the Millennium Development Goals (MDGs) world commitments. Yet, lack of access to safe drinking water and adequate sanitation remain widespread global issues. According to the WHO and the UNICEF Joint Monitoring Programme (JMP), in 2015, 663 million people were estimated to live without access to an improved water source and 2.4 billion people were still lacking access to improved sanitation facilities. Target 7C of the MDGs was to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation (i.e. improved water supply and sanitation services). Despite the MDG Target 7C achievement with regard to drinking water, 42.5% of the world population did not have access to water on premises and needed to fetch it (UNICEF/WHO 2015). For sanitation, the target was not achieved although significant improvements were observed. Open defecation (OD) continued to be practised by 13% of worldwide population among which nine out of ten were living in rural areas (UNICEF/WHO 2015).

The apparent global progress in achieving the MDGs relative to drinking water masks the very limited progress in some segments of the population. Rapid urbanization worldwide has led to the necessity of improving urban services but has also exacerbated inequalities between urban and rural populations (Bain et al. 2014b, Wolf et al. 2013). At the end of the MDGs, further progress was called for through the inauguration of the Sustainable Development Goals (SDGs) that will extend until 2030. The latter's targets aim to: achieve equitable universal access to safe and affordable drinking water; achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations (e.g., all children, youth, persons with disabilities, people living with HIV/AIDS, older persons, indigenous peoples, refugees and internally displaced persons and migrants) by 2030 (WHO/UNICEF 2017a) .

The population using *safely managed drinking water services* (i.e., an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination) and *safely managed sanitation services* (i.e., improved facilities which are not shared with other households and where excreta are safely disposed *in situ* or transported and treated off-site) were set as improved indicators used by JMP to monitor progress towards the SDGs. This adjustment reduced the baseline proportion of the population considered as having access to safe and affordable drinking water (71% of the global population) or adequate and equitable sanitation (39% of the global population) in comparison with the MDGs, but is likely to increase the accuracy of the indicators (WHO/UNICEF 2017a). The current population with access to safely managed drinking water can be further broken down to 85% and 55% in urban and rural areas, respectively. With regard to safely managed sanitation service, the proportion of the global urban and rural population with access was determined to be 43% and 35%, respectively (WHO/UNICEF 2017a).

Agenda 2030 called for "leaving no one behind" (WHO/UNICEF 2017a), advocating for efforts aimed at reducing the service gaps and reaching the populations who are furthest behind (i.e., low income, rural, etc.). Households using unimproved drinking water sources including surface water and practising open defecation are the most likely to need assistance. As primarily responsible for households' water supply, sanitation and hygiene, women's and girls' lives are even further driven by a lack of access to basic services (Chipeta 2009, Graham et al. 2016).

Access being usually greater in urban areas, global trends show that the service level of water and sanitation increases with the wealth of populations (Cassivi et al. 2018c, Oageng and Mmopelwa 2014, Seyoum and Graham 2016, WHO/UNICEF 2017a). Factors such as climate change and population growth are expected to increase vulnerability to water stress and affect the adaptability of sanitation systems, especially for vulnerable populations in low- and middle-income countries and other low resource contexts with limited coping strategies (Fulco 2009, Sherpa et al. 2014).

Malawi is ranked among the poorest countries globally (GDP per capita = 389 US$) and relies greatly on official development assistance (World Bank 2018); it has experienced a significant population growth in the last decades. Water supply and sanitation facilities have improved following major investments in the sector, however, foreign aid interventions and allocations in water supply and sanitation services weren't provided to the areas with the highest needs as most were implemented in settings with greater existing infrastructure (Marty et al. 2017, Wayland 2017). The MDG water-related target was achieved whereas moderate progress was made in sanitation (UNICEF/WHO 2015). In 2015, it was reported that 87% of the national population had access to an improved water source (i.e. piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water) and 41% had access to an improved sanitation facility (i.e. flush/pour flush to piped sewer system, septic tanks or pit latrines; ventilated improved pit latrines, composting toilets or pit latrines with slabs) (WHO/UNICEF 2018). As such, it is likely that these statistics were driven by the progress made in areas that did not have the greatest need (Adams 2018).

With regard to the SDGs, the number of people with safely managed drinking water and sanitation services in Malawi is expected to decrease from the old improved/unimproved metric, when accounting for additional criteria of access (Cassivi et al. 2018b, Cassivi et al. 2017a, Smiley 2017). Unfortunately, information on safely managed services in the country remains unknown due to data unavailability (e.g. water quality and contamination, excreta disposal and treatment). Significant inequalities are nevertheless expected to rise as in similar contexts where water quality is generally worse in rural areas (Bain et al. 2014a, Bain et al. 2012b, Bain et al. 2014b). Furthermore, the use of improved water and sanitation facilities is greater in the wealthiest quintiles, confirming the necessity to target the most vulnerable populations (WHO/UNICEF 2017a).

There is a need to focus on the variation in lack of access to water and open defecation in the different geographic and socio-economic groups of the population using classification such as region, development type (urban/rural), wealth or education level (Galan et al. 2013, Hopewell and Graham 2014). However, research focusing on disaggregated data is limited, and the extent of such variations is not well known. Using the case study of Malawi, we compare the indicators of access to water and sanitation across those four categories. Further, as individuals who have neither good water access nor good sanitation are those who should be first addressed as they are the furthest behind we consider these two measures to identify where priority should be placed for interventions/improvements.

The objectives of this study are to describe emerging trends on progress and inequalities in water supply and sanitation services over a 25-year period (1992 - 2017) and to identify areas where the proportion of the population without basic access to water and practising open defecation remains among the most vulnerable in Malawi. This is a timely exercise to identify and target groups that were left behind and help reach, by 2030, the targets set in the SDGs.

Methods

This study was conducted using existing national surveys conducted in Malawi. Data sources including UNICEF Multiple Indicator Cluster Surveys (MICS), USAID Demographic and Health Surveys (DHS), and Malaria Indicators Survey (DHS-MIS), all of which are harmonized household surveys. Household data for Malawi were downloaded and extracted for each year publicly available, which include data from 1992 to 2017 (Table 2.1) (UNICEF 2019b, USAID 2019). Appended datasets included a total sample of 154,603 Malawian households covering a period of 25 years. DHS and MICS surveys are designed with a stratified, two-stage cluster design, which aims to provide representative estimates for the geographic regions, urban/rural areas and wealth quintiles. Random sampling and data privacy don't allow one to determine if households were repeatedly selected across years.

Table 2.1. Information on data sources included in analysis.

Year	Survey	Sample (n)
2017	DHS-MIS	3,729
2015-16	DHS	26,361
2014	DHS-MIS	3,405
2013-14	MICS	28,479
2012	DHS-MIS	3,404
2010	DHS	24,825
2006	MICS	31,200
2004	DHS	13,664
2000	DHS	14,213
1992	DHS	5,323
	Total	**154, 603**

The use of longitudinal data required pre-processing as MICS and DHS questionnaires have been modified and conducted in different rounds over time. All possible differences between years were taken into account and data from each year were systematically recoded and categorized to ensure homogeneity of the variables prior to appending and analysis. The JMP methodology for compilation and classification was replicated to produce the most accurate estimates (WHO/UNICEF 2018). Household weights as reported by DHS and MICS (i.e., inverse of the household selection probability multiplied by the inverse of the household response rate in the stratum) were multiplied by the number of household members to calculate population weights (DHS/ICF 2018, WHO/UNICEF 2018). Population weighting was used to produce estimates of coverage for access to water and open defecation at the individual level, as applied to monitor global progress in access to drinking water and sanitation services.

Data analysis

Relevant data on drinking water supply and sanitation, including type of water source and sanitation facilities, were disaggregated to target the most vulnerable populations and emphasize the lingering lack of access (Eagin and Graham 2014). The principal indicators were reduced to the following due to their availability and consistency across surveys over time: 1) the proportion of the population without access to an improved water source located within 30 minutes (i.e., basic access); 2) the proportion of the population practising open defecation; and 3) the proportion of the population without access to an improved water source located within 30 minutes and practising open defecation.

Trends in access to water and open defecation were assessed using explanatory and groupings variables available in DHS and MICS surveys including: source of drinking water (*n*=152 160), round-trip time to collect water (minutes) (*n*=150 600) and type of toilet facility (*n*=152 097). Classification of improved and unimproved water technologies followed JMP classification for SDG monitoring. Therefore, ambiguous categories that were used in the first rounds of surveys (i.e., 1992, 2000, 2004) were classified as follows: “spring” and “public well” as unimproved water technologies and “traditional pit latrines” as unimproved sanitation technology. Analysis was conducted by grouping data in regions (i.e., Northern, Central and Southern), areas (i.e., urban/rural), wealth index which was a composite measure of a household's cumulative living standard as defined by DHS and

MICS (i.e., poorest, poorer, middle, richer, richest), and education level of the head of the household (i.e. no education, primary education, secondary education and higher). According to the National Statistical Office urban areas are Lilongwe City, Blantyre City, Mzuzu City, and the Municipality of Zomba. Analysis was limited to variables that were available across the data sets. In random cases where data were missing, the households were excluded from specific analysis.

Descriptive statistics including measures of frequency (i.e., count, percent, frequency) and measures of variation (i.e., point difference, percent change) were used to summarize and assess progress and inequalities over time using disaggregated data. Analysis was conducted using Stata SE14.

Results

Trends and Progress

Drinking Water

The proportion of the population without basic access to drinking water (i.e., improved water sources within 30 minutes) decreased from 1992 to 2017 reflecting considerable progress, as shown in Table 2.2 which includes aggregate and disaggregated data. At the national level, the population without access to an improved water source within 30 minutes walking distance decreased from 57% to 22% representing a percentage change of 62.01%. The greatest improvement was observed between 2015 and 2017 where the proportion of the population without access considerably decreased at the national level reflecting similar change at the disaggregated levels. Although household access was improved, the proportion of women who were responsible for fetching water remained roughly the same over time (varying between 84% and 87% from 2006 to 2014).

Progress towards providing basic access to water was greater in rural areas– where 83% of the Malawian population lives (World Bank 2018) – than in urban areas. In rural areas, the proportion of the population without access went down from 63% to 25% over the 25-year period. Although the percentage point change from 1992 to 2017 was greater in rural areas, the percentage change attributable to improving access in urban areas was higher with a decrease from 13% to 5%. The gap between urban and rural populations remains one of the greatest among all groups and persists as relative percent change was similar (40% relative change) over time.

Across regions, similar progress was made in the Central and Southern regions – where respectively 43% and 44% of the population lives– as the proportion of the population without basic access was reduced by 37% (NSO Malawi 2008). Less progress was observed in the Northern Region where the population without basic access decreased from 60% to 31%. The proportion of the population without access remains the highest in this region accounting for the least populous in the country.

The greatest progress within the wealth quintiles was among the poorest group in which the percentage of the population without access was lower than in poor and middle upper wealth quintiles. At the opposite end, the richest group had the least progress in terms of percentage point change, which is explained by already high levels of service. Overall, the proportion of the population without access to an improved water source within 30 minutes was at least halved in all wealth quintiles.

Significant disparities were observed between education levels: the proportion of the population without basic access increased between 1992 and 2017 in households with secondary or higher level of education. This is likely explained on account of the fact that the latter are probably urban while most programming targets rural uneducated. Progress was, however, observed in groups without education and primary education. Although the percentage of the population without basic access was reduced by one third from 1992 to 2015 for all groups, it remained higher for the population with secondary level education. The difference in access to drinking water with regard to education illustrates the highest inequalities among all groups.

Open Defecation

The number of people practising open defecation (OD) was reduced at the national scale from 1992 to 2017 (

Table 2.3). Over the 25-year period, OD was reduced by 19% (a reduction from 25% to 6%). An important difference between rural and urban areas was observed in 1992, where 28% and 2% of the population were practising open defecation, respectively; this gap then narrowed in the following years. It is possible that efforts were made towards improving access to sanitation in rural areas where most of the population lives. The percentage of the population practising open defecation was reduced by three quarters, dropping from 28% to 7% from 1992 to 2017. Although the proportion of people practicing OD was already low in urban areas, it was nearly halved over the 25-year period reaching 1% of the urban population.

Progress was greater in the central region where OD prevalence was the highest at the baseline year with a percentage change of 83% (between1992- 2017). Lower progress was observed in the Southern Region which had the highest proportion of the population practising open defecation.

With regard to the wealth index quintiles, the proportion of the population practising open defecation was reduced by more than three quarters in all groups except the middle wealth group where the proportion was nearly halved. The gap between the poorest and richest quintile was reduced between 1992 and 2017. The most important percentage change was observed in the richest group reaching nearly 0% in 2017.

Open defecation was reduced by three quarters in the population without education or with primary education, reaching fewer than 10% in 2015. Progress over the 25-year period was lower in households where in the household head had secondary or higher education.

Water and Sanitation

The trends show that the proportion of the population without access to an improved water source within 30 minutes and practising open defecation was even further reduced than individual progress in water and sanitation areas (Table 2.4). At the national scale, the percentage of the population without basic access to water and practising open defecation decreased nearly 90% from 16% to 2% over the 25-year period. Results show important progress in demonstrating improvement in access for either or both water and sanitation among the populations that were further behind.

Progress in the proportion of the population without access to water and practicing open defecation was similar in all regions over the years. Improvement in the rural areas led to a reduced gap of access between both areas although disparities remain. Most people without access to basic water and sanitation services were living in rural areas below the middle income wealth quintiles.

As education levels increased, the proportion of the population without access to water and practicing open defecation was reduced. Progress from 1992 to 2017 was similar in households without education and those with primary education as opposed to secondary level and higher where most of the population already had higher levels of access to water and sanitation at the baseline year.

Table 2.2. Population without basic access to drinking water (1992-2017) (DHS, MICS).

		Population without basic access to water (%)										Percentage point difference	Percent change*
		1992	**2000**	**2004**	**2006**	**2010**	**2012**	**2013**	**2014**	**2015**	**2017**		
NATIONAL		57.18	50.3	50.35	48.52	39.85	28.37	44.06	29.28	37.11	21.72	-35.46	-62.01
REGION	Northern	59.51	44.85	48.48	40.06	34.32	29.79	36.85	33.30	33.94	31.02	-28.49	-47.87
	Central	59.63	53.36	52.24	48.77	43.19	31.26	41.34	31.29	38.50	22.79	-36.84	-61.78
	Southern	54.68	48.87	49.12	50.28	38.08	25.12	48.10	25.59	36.69	18.14	-36.54	-66.83
AREAS	Rural	57.18	50.3	56.75	53.42	43.6	31.24	48.72	33.33	41.17	24.95	-38.45	-60.65
	Urban	63.4	56.17	16.42	21.1	20.06	11.2	14.85	9.55	13.25	4.89	-8.48	-63.43
WEALTH INDEX	Poorest			66	59.40	51.70	42.70	53.65	37.02	46.23	24.65	-41.35	-62.65
	Poorer			61.02	56.06	46.20	30.81	50.63	37.79	42.10	27.08	-33.94	-55.62
	Middle			55.58	53.15	43.94	31.49	50.25	34.45	41.44	27.93	-27.65	-49.75
	Richer			50	47.74	37.47	28.25	45.66	30.16	38.48	20.61	-29.39	-58.78
	Richest			19.49	27.90	20.28	8.60	20.12	6.95	17.45	8.41	-11.08	-56.85
EDUCATION LEVEL	None	63.77	58.79	58.35	55.04	44.88	-	50.29	-	42.49	-	-21.28	-33.37
	Primary	58.48	52.97	54.01	51.22	43.41	-	47.69	-	40.09	-	-18.39	-31.45
	Secondary	24.90	23.51	27.86	31.12	24.27	-	32.80	-	26.52	-	1.62	6.51

** From baseline year to end line year. First available value was used when year 1992 wasn't available.*

Table 2.3. Population practising open defecation (1992-2017) (DHS, MICS).

		Population practising open defecation (%)										Percentage point difference	Percent change*
		1992	**2000**	**2004**	**2006**	**2010**	**2012**	**2013**	**2014**	**2015**	**2017**		
NATIONAL		24.76	16.41	14.45	12.08	9.83	13.45	4.90	11.27	5.33	6.02	-18.74	-75.69
REGION	Northern	18.41	13.41	14.29	11.79	13.21	14.29	11.79	13.21	14.01	3.64	-14.77	-80.23
	Central	28.19	17.89	16.25	10.75	10.69	13.02	4.30	10.25	4.34	4.86	-23.33	-82.76
	Southern	23.59	15.81	12.79	13.45	8.10	13.70	5.70	9.31	6.23	7.66	-15.93	-67.53
AREAS	Rural	27.97	18.88	16.22	13.83	11.23	15.12	5.60	13.03	6.15	6.94	-21.03	-75.19
	Urban	2.23	1.44	5.05	2.26	2.46	3.44	0.49	2.69	0.50	1.24	-0.99	-44.39
WEALTH INDEX	Poorest	-	-	42.78	25.22	26.18	31.45	15.13	22.51	15.30	15.09	-27.69	-64.73
	Poorer	-	-	15.99	16.48	11.60	17.05	4.76	16.63	6.03	5.16	-10.83	-67.73
	Middle	-	-	7.68	10.68	7.30	11.20	3.17	11.67	2.80	7.43	-0.25	-3.26
	Richer	-	-	5.16	6.72	3.74	6.79	1.32	5.23	2.24	1.78	-3.38	-65.50
	Richest	-	-	0.81	1.7	0.6	0.84	0.1	0.33	0.35	0.65	-0.16	-19.75
EDUCATION LEVEL	None	35.59	26.88	21.33	18.17	14.92	-	8.88	-	8.38	-	-27.21	-76.45
	Primary	22.40	15.16	15.02	12.22	10.44	-	5.22	-	5.80	-	-16.6	-74.11
	Secondary	3.56	3.10	3.58	4.03	3.15	-	1.59	-	2.19	-	-1.37	-38.48

** From baseline year to end line year. First available value was used when year 1992 wasn't available.*

Table 2.4. Population without basic access to water and practising open defecation (1992-2017) (DHS, MICS).

		Population without basic access to water and practising open defecation (%)										Percentage point difference	Percent change*
		1992	**2000**	**2004**	**2006**	**2010**	**2012**	**2013**	**2014**	**2015**	**2017**		
NATIONAL		16.07	10.12	9.06	7.41	4.64	4.49	2.76	4.73	2.45	1.75	-14.32	-89.11
REGION	Northern	8.96	8.25	5.76	4.41	4.28	2.03	9.44	2	1.81	-11.38	-86.28	-80.23
	Central	11.43	10.22	6.43	5.27	5.37	2.17	3.82	2.06	1.53	-18.1	-92.21	-82.76
	Southern	9.22	8.20	8.76	4.08	3.71	4.42	3.49	2.92	1.94	-12	-86.08	-67.53
AREAS	Rural	11.68	10.36	8.54	5.35	5.11	3.17	5.48	2.85	2.08	-16.15	-88.59	-75.19
	Urban	0.65	2.16	1.08	0.88	0.82	0.19	1.11	0.1	0.03	-0.84	-96.55	-44.39
WEALTH INDEX	Poorest	-	28.40	15.54	13.55	13.65	8.69	10.02	7.58	4.52	-23.88	-84.08	-64.73
	Poorer	-	9.88	10.42	5.03	5.10	2.52	6.80	2.51	1.66	-8.22	-83.20	-67.73
	Middle	-	4.03	6.13	2.99	2.05	1.86	5.40	1.23	2.13	-1.9	-47.15	-3.26
	Richer	-	2.65	4.33	1.59	1.70	0.68	1.44	0.88	0.43	-2.22	-83.77	-65.50
	Richest	-	0.45	0.89	0.16	0	0.05	0	0.09	0.03	-0.42	-93.33	-19.75
EDUCATION LEVEL	None	17.14	14.14	11.38	7.25	-	4.81	-	4.23	-	-18.63	-81.50	-76.45
	Primary	9.08	9.34	7.40	4.93	-	3.05	-	2.64	-	-12.08	-82.07	-74.11
	Secondary	1.92	1.48	2.36	1.24	-	0.69	-	0.81	-	-1.2	-59.70	-38.48

** From baseline year to end line year. First available value was used when year 1992 wasn't available.*

Population

Although improvements in terms of access to water and open defecation were generally observed between 1992 and 2017, important variations were noted between 2010 and 2017. The proportion of the population without access to an improved water source within 30 minutes and practicing open defecation followed a decreasing trend from 1992 to 2010 and peak fluctuated until 2017 (Figure 2.1). Further analysis was conducted to investigate the impact of the type of survey data on trends and progress. The observed peaks in data are likely attributable to the type of surveys as years 2012, 2014 and 2017 were conducted under DHS-MIS (Malaria Indicators Survey) with smaller sample sizes. The proportion of the population without access to drinking water reached the lowest values during these years while higher proportions of open defecation were observed. The DHS-MIS survey differed from MICS and Standard DHS by the smaller sample size which implies potential sampling differences that explain fluctuations in estimates. Disaggregation of the DHS and MICS survey data highlights the discrepancy in the distribution of the sample among population groups (Table 2.5).

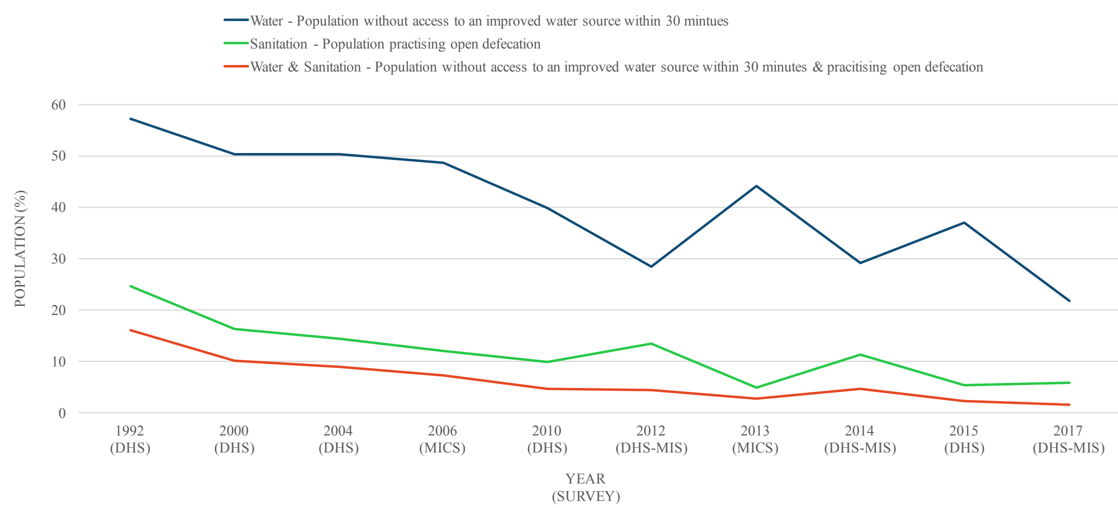

Figure 2.1. Proportion of the population without access to water and sanitation over the years (1992-2017).

Table 2.5. General distribution of the national population drawn for DHS and MICS surveys.

		General description – National Population (%)									
		1992	**2000**	**2004**	**2006**	**2010**	**2012**	**2013**	**2014**	**2015**	**2017**
REGION	Northern	28.01	16.07	11.86	19.23	17.43	15.01	18.35	28.52	18.84	33.31
	Central	33.14	34.01	36.25	34.62	33.75	39.48	33.46	35.3	33.21	33.33
	Southern	38.85	49.92	51.9	46.15	48.82	45.51	48.19	36.18	47.95	33.36
AREAS	Rural	25.15	18.86	12.62	11.18	11.72	30.99	14.31	35.57	18.93	39.96
	Urban	74.85	81.14	87.38	88.82	88.28	69.01	85.69	64.43	81.07	60.04
WEALTH INDEX	Poorest			23.54	20.73	22.18	18.04	21.26	16.95	19.52	13.46
	Poor			20.85	21.32	21.36	16.39	19.91	17.42	19.47	13.52
	Middle			20.18	20.16	20.52	17.33	20.01	17.8	19.13	14.03
	Richer			19.23	19.81	19.67	18.04	19.5	19.94	19.7	19.9
	Richest			16.2	17.97	16.17	30.2	19.32	27.9	22.18	39.1
EDUCATION LEVEL	None	28.48	25.33	25.76	21.67	19.05		16.41		15.91	
	Primary	58.64	59.46	58.04	60.12	61.03		61.91		56.46	
	Secondary	12.87	15.2	16.2	18.21	19.92		21.68		27.63	

In order to explore representativeness, survey data were compared with national population data drawn from the Malawi National Statistics Office Census and The United Nations Population Division's World Urbanization. A comparison of the total rural/urban population ratio shows an important contrast with survey data particularly in the years where DHS-MIS were conducted (Figure 2.2). Trends with regards to the rural population in DHS and MICS surveys across time (R^2=0.1) don't follow the distribution of the population as reported in national census over the relevant years (1987-2017) (R^2=0.9). In 2017, the survey population living in rural areas was 60% compared with the actual population where it was estimated to be 83%. The rural population in the sample for the years 2012, 2014 and 2017 was underestimated from 15% to 23% compared to census population which likely explains the difference observed in the trends of access to drinking water and sanitation (Figure 2.2).

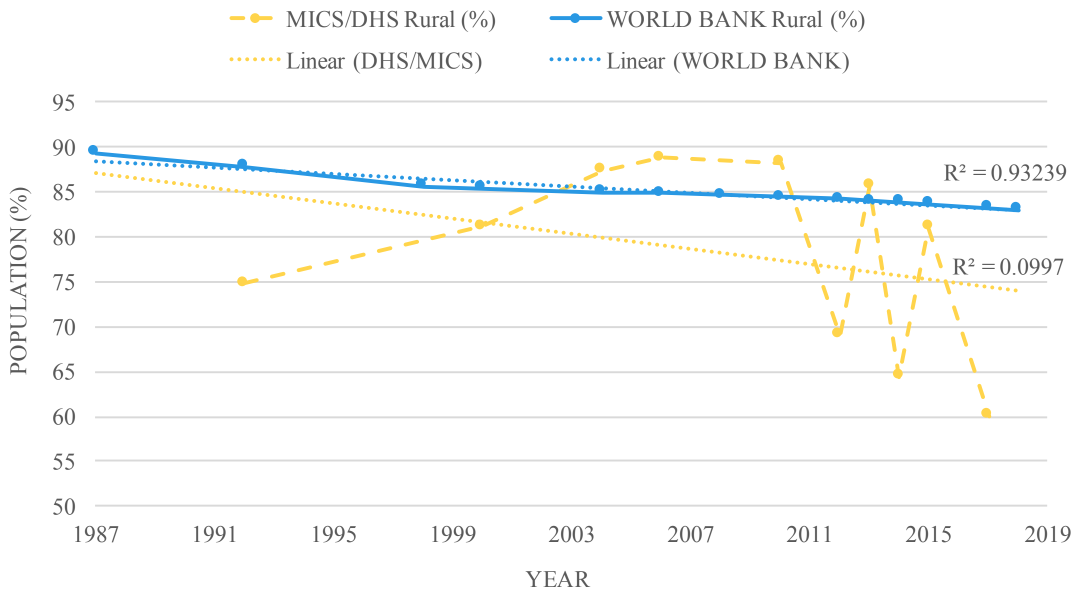

Figure 2.2. Comparison of the distribution of the rural population in survey sample and total population.

Variations in the distribution of the population across wealth living standards between rural and urban areas are also observed in the survey sample. These variations are exacerbated in the years where DHS-MIS were conducted. In urban areas, the richest group is higher represented compared the other groups which likely represents the actual distribution of the population (Figure 2.3). The opposite pattern is observed in rural areas where the richest households represent lower proportions of the population (Figure 2.4). The other groups are similar in terms of distribution and generally follow the same trends across the years.

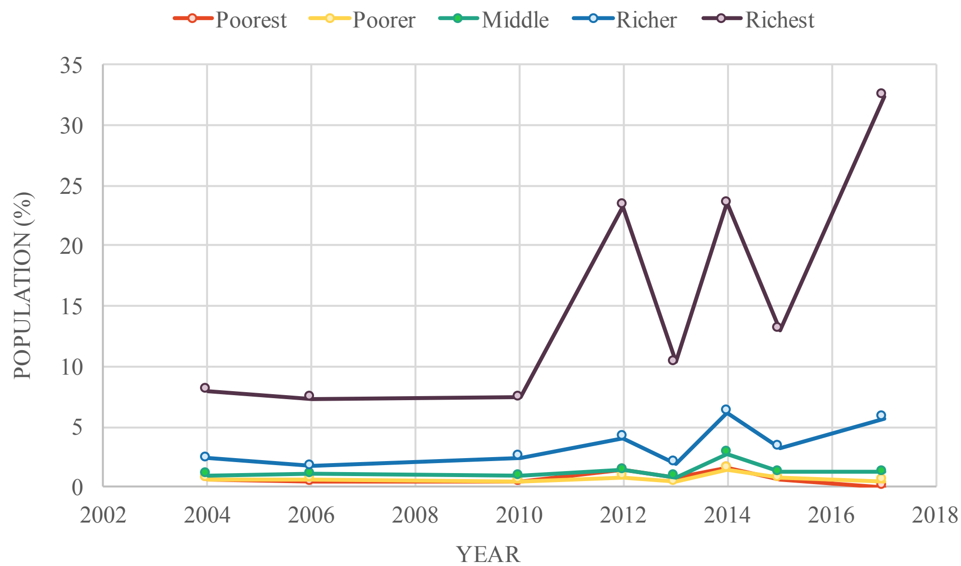

Figure 2.3. Trends of the population by wealth quintiles in urban areas (%)

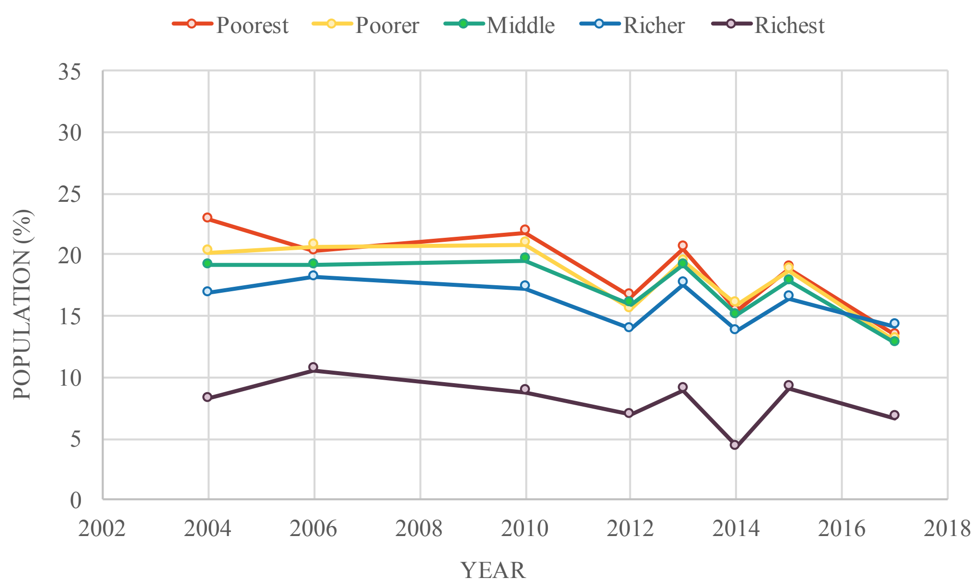

Figure 2.4. Trends of the population by wealth quintiles in rural areas (%)

Finally, variations were also observed with respect to the distribution of the sample population in the three regions of Malawi (Figure 2.5). Data from the national population (NSO Census) shows limited changes in the distributions of the population in the different regions of the country over the years. Data from DHS and MICS generally follow the population reported in national census as most inhabitants are located in Central and Southern regions. Differences were, however, observed for the years 1992, 2014 and 2017 where the survey sample was equally distributed among the three regions. Such variations in the sample population don't represent the population in the country and likely influence the estimates at the country level.

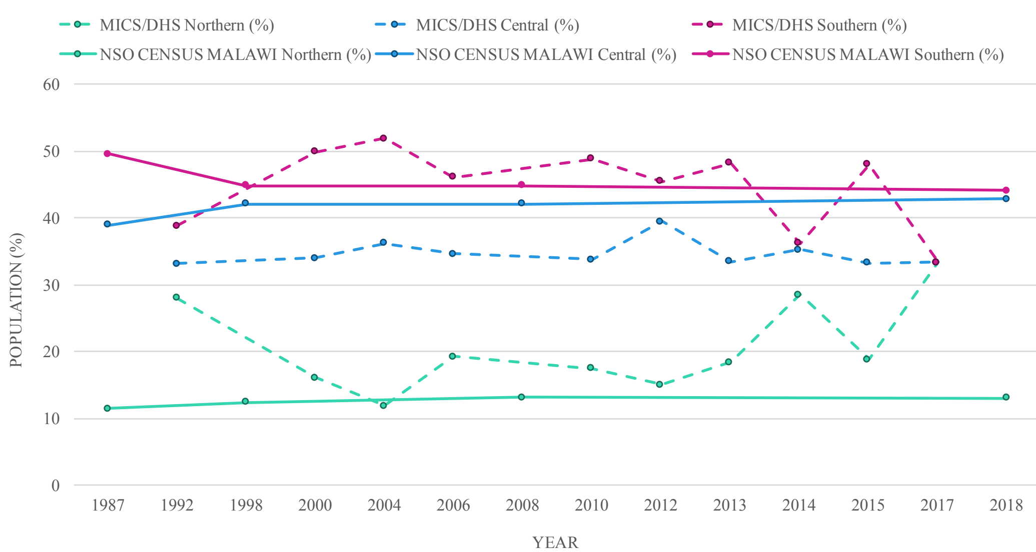

Figure 2.5. Distribution of the population in the regions with comparison of the survey sample and total population.

Inequalities and Vulnerability

Following the trend analysis, end-line data were used to further study where lack of access remains the most critical and who is the most vulnerable in the country. Data from DHS 2015 were used as distribution of the sample data was shown to be more similar to the national global population than DHS 2017. The largest sample size also demonstrated a higher likelihood of following over last decades' national estimates.

Drinking Water

Disaggregation of the population without access to an improved water source located within 30 minutes show the distribution of the population in the different groups and highlights the ones that are the most vulnerable (Figure 2.6). The population without access is mostly within the Central and Southern regions, with a lower proportion in the Northern region. More than three quarters of the people without access were living in the rural Central or Southern areas. Among all regions, most of the population lacking access lives in rural areas. Of note, the populations lacking access were mostly from richer households in the rural, Northern areas. The percentage of the population without access decreased as wealth increased in the Central Region. The population without access to basic drinking was similar in all wealth groups of the Southern Region with the exception of the richest where the proportion was the lowest.

Open Defecation

In 2015, 5% of the national population was reported to practice open defecation. Despite significant progress in most of the groups, the distribution of the population practising open defecation was not uniform across groups (Figure 2.7). Concentrated in the Central and Southern regions, most of the populations practising open defecation were living in rural areas. Overall, 54% of the population practising open defecation in Malawi was located in rural Southern areas among which 31% were living under the poorest wealth quintile. There was almost no one in the urban areas and rural richest quintiles practising open defecation in 2015.

Figure 2.6. Distribution of the population without access to an improved water source located within 30 minutes (%) (2015).

Figure 2.7. Distribution of the population practising open defecation (%) (2015)

Water and Sanitation

In 2015, 2% of the population in Malawi didn't have access to an improved drinking water source within 30 minutes of their household and were still practising open defecation. A general negative association between open defecation and wealth is observed as the practice decreases as wealth increases (Figure 2.8). More than half of the people living without such access were located in the Southern Region and were mainly part of the poorest quintile of the population. Among all regions, the proportion of the population without access to basic water and sanitation supply was zero (or close to it) in the urban areas and the richer and upper quintiles in all areas.

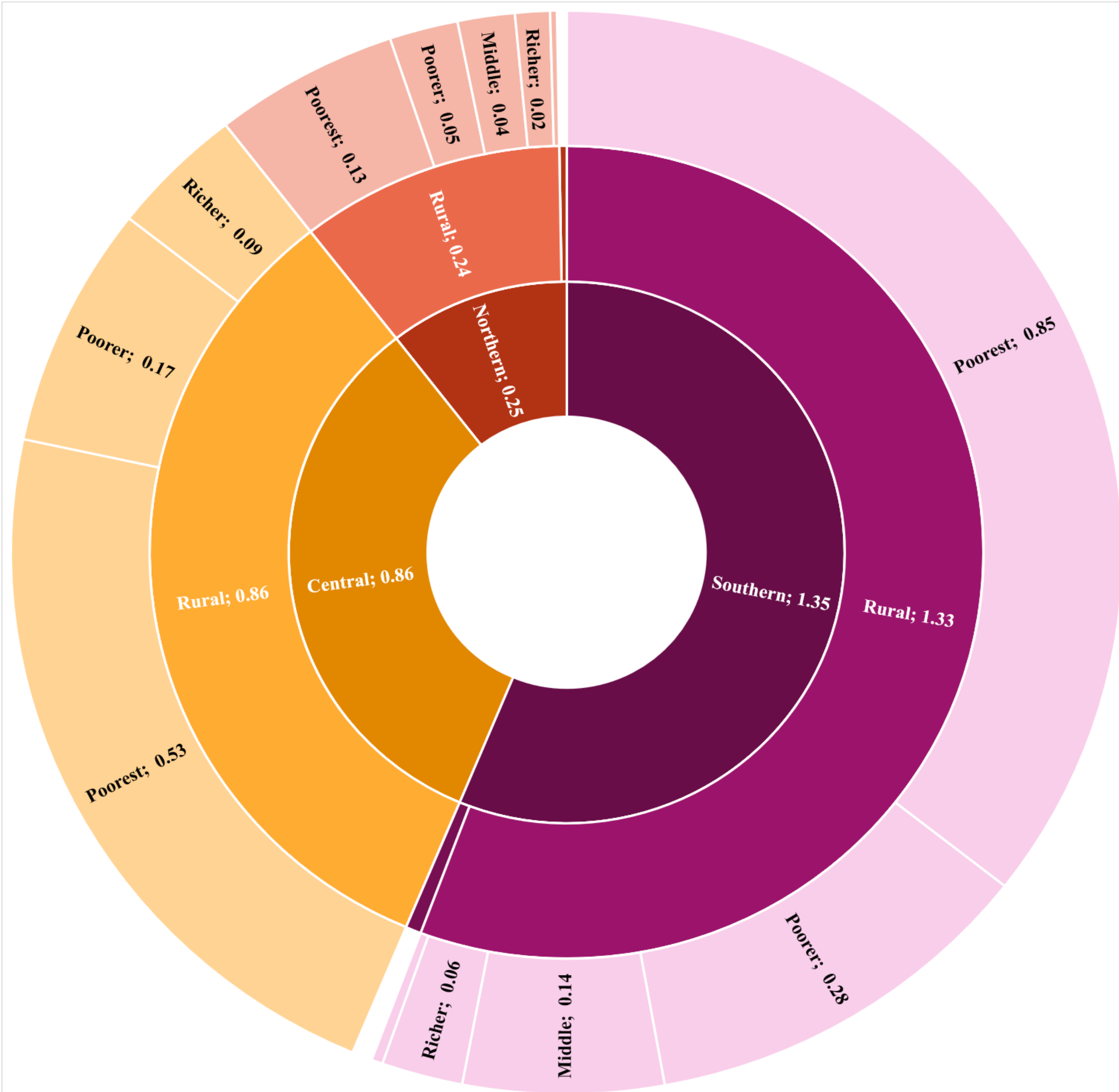

Figure 2.8. Distribution of the population without access to basic drinking water services and practising open defecation (%) (2015).

Discussion

General Progress

Progress in access to water and sanitation in Malawi is observed in all groups of the population, including region, area, education level and wealth, over the 25-year period for which data were available. The largest progress is generally observed in the groups that were furthest behind at the baseline year (e.g., rural, poorest, uneducated), which likely reflects good targeting. Although more people gained access in those groups, i.e. the largest segment of the population, the percentage of the population without access to water or practising open defecation continued to be the highest, which is consistent with studies conducted in other countries (Eagin and Graham 2014). This reflects that most progress in terms of improving access was observed in the Central and Southern regions. Over time, these regions have narrowed the gap with the Northern Region where lower density along with greater access at the baseline year were reported. Results demonstrated low regional inequalities in terms of access in the country and this is consistent with Pullan et al. (2014)) findings that relate to the same data.

Improvement in access to basic water and sanitation services in the country is likely attributable to the important investment in the sector over the last decades. Malawi received one of the largest per capita amounts of aid (ODA per capita = 1.07$) within the water sector between 2000 and 2010 (Bain et al. 2013). Galan et al. (2013) demonstrated a significant association between per capita aid disbursement for basic water and sanitation and proportion of the population practising open defecation reduction. The higher proportion of the population lacking access to each water and sanitation separately as opposed to both shows that access was mostly improved for one service – namely water – but not necessarily to each of them. It is evident that improving access to both water and sanitation is indispensable to benefit the population (Bartram and Cairncross 2010).

The implementation of the Open Defecation Free (ODF) Malawi Strategy 2011 has raised awareness in the country by highlighting the need for involvement from Ministry of Agriculture, Irrigation and Water Development, Ministry of Health, Ministry of Education and key line ministries in collaboration with development partners, NGOs, private sector, communities and key sector players in the sector. Such efforts likely accelerated progress as important change is observed in the rural areas from 2012 onwards. Minimal progress was observed in reducing open defecation in urban areas, and is not surprising considering that ODF Malawi Strategy only focused on rural areas and hasn't specifically tackled the most vulnerable and marginalized group of the population (e.g. people with disabilities, the elderly, women, children and youth)(Taulo et al. 2018).

Despite the fact that fewer people gained access in groups where access was the greatest at the beginning of the 25-year period, results demonstrated that percentage change improvement still occurred over the years. The constant progress across the different parts of the population, however, suggests the positive effect of recent underlying efforts to improve access to water and sanitation in Malawi. The remaining population (though a small percentage of the total) without access to an improved water source within 30 minutes and/or practising open defecation remains the hardest to reach and should be targeted in view of ensuring universal and equitable access for all by 2030.

Urban and Rural Areas

It is evident that the proportion of the population gaining access was larger in rural areas for both water and sanitation services. Different rates of progress in both groups led to a reduction in the gap between rural and urban areas. The population without access to an improved drinking water source within 30 minutes and/or practising open defecation was greatly reduced in both areas. It should be noted that access to water and sanitation was already greater in the urban areas at the beginning of the 25-year period which explains why fewer people gained access. Nevertheless, results demonstrated important progress and similar percentage changes in the urban areas supporting the broad range of people targeted in terms of improvements.

Improvements in access in the urban areas were observed to follow slight urban population growth in Malawi. Overcoming progress despite urbanization may suggest that people moving from rural to urban areas also get at least basic access to water and sanitation or that further efforts were put forward improving access for the vulnerable urban populations. Using global aggregate data, Bain et al. (2013) show that progress in urban household connections may be positively correlated with overall coverage in rural areas.

As improvements may become stagnant with urban population growth, addressing the needs of marginalized populations remains essential to reach universal access (Adams 2018). Previous studies shed a light on the fact that some groups in urban areas, i.e., those living in urban slums, may be even more vulnerable than the population in rural areas (Lungu et al. 2019). Lack of access to water and sanitation in urban areas is mainly a burden in peri-urban areas, and this has been documented in Blantyre and Mzuzu (Chipeta 2009, Wanda et al. 2012). The importance of targeting beyond the disadvantaged rural, towards vulnerable urban population has previously been put forward (Chipeta 2009, Lungu et al. 2019) and is reinforced by the data presented here that show little progress in urban areas. Further disaggregation of urban populations, by taking into account peri-urban and informal settlements, would strengthen estimates (Bain et al. 2014b) as UN-Habitat (2013) estimated that nearly 70% of the urban population was living in informal settlements in Malawi.

Wealth and Socioeconomic Status

Household wealth and education levels were also observed to influence trends in access to water and sanitation. Generally, a reduction of the population without access to water and sanitation was greater in the lowest quintiles where baseline data was the highest. More people gained access to basic services in the lowest quintiles although the percentage change was similar across quintiles. Results highlight that the different rate changes across quintiles resulted in more equitable access to water across quintiles by narrowing the gap between the poorest and richest populations. Such findings are supported by previous studies that have found a significant association between socio-economic status and access to water and sanitation services (Adams 2018, Eagin and Graham 2014, Seyoum and Graham 2016).

Small variations in the percentage of the population without access to an improved water source were observed but greater inequalities with regard to practising open defecation were highlighted between each wealth quintile. In 2015, the percentage of the population lacking access to improved drinking water sources within 30 minutes in rural areas was almost heterogeneous across quintiles. In the Northern and Southern regions, a greater percentage of the population within the richer and middle quintiles were lacking access to drinking water.

A higher income would generally allow individuals to live where better infrastructure exists. Even where infrastructure for water does not exist, those with greater wealth may still occupy locations with better access to infrastructure such as water supply and sanitation. The important difference between urban and rural population, however, appears to further highlight inequalities than wealth in the country. These results confirm previous findings which have shown that rural and urban areas faces the strongest inequities (Seyoum and Graham 2016). Understanding the role of socio-economic status will be critical for designing policies targeting the most vulnerable households among the population (Adams 2018). No data are currently available to define the actual distribution of wealth across the country which limits further comparison with the population.

Leave No One Behind

Results from this study demonstrated that although improvements have been made, significant parts of the population still have limited access and are forced to practice open defecation. Such findings highlights the need to target the most vulnerable and marginalized populations (Pullan et al. 2014). Looking at trends by wealth draws attention to the breadth of reconsidering disadvantaged rural thinking (Lungu et al. 2019). Women play a central role in water and sanitation as they continue to perform most of the water fetching. The time and energy associated with fetching water further exacerbates gender inequalities and reduces women's potential for empowerment by limiting opportunities (e.g. education, paid work, healthcare and childcare) and increasing the risk of injuries and exposure to abuse and violence (Curtis 1986, Geere 2015). Women and girls practicing open defecation are also exposed to sexual exploitation and psychosocial stressors, which further compromise their dignity, health and well-being (Saleem et al. 2019). Improving access to water, sanitation and hygiene is a key driver to improve women's and girls' lives. Gender equity in terms of access to water and sanitation should be further investigated to address women's and girls' needs for empowerment. Acknowledging the different context between groups of the population (e.g., urban/rural) and targeting interventions to appropriate situations is essential to leave no one behind (Adams and Smiley 2018).

Limitations

Certain limitations regarding data analysis must be stated. This study used readily available large-scale data collected as part of the MICS and DHS surveys and is thus subject to data quality and accuracy controls. Indicators selected for this study were used as they were the most consistent across the years. Open defecation is not the only one towards safely managed sanitation services and may be considered as the simplest reduction proxy to monitor access to sanitation.

Although the surveys are said to be nationally representative, a variation in data estimates with regards to the type of survey conducted by DHS was observed. The trends of access show a difference between the DHS standard and MIS surveys which could be attributable to the use of a different sampling frame. This study had a descriptive aim and doesn't include measures of association or temporality. The relationship between access to water and sanitation and other explanatory factors should be further explored to establish causation.

It should also be noted that survey estimates are drawn from self-reported data which may introduce biases, such social desirability response bias (e.g. conformity, sensitivity to open defecation, hope for better services), and compromise data reliability and validity (Guest et al. 2005, Van de Mortel 2008). Additionally, the differentiation between areas are based on the country's urban-rural definition. It remains unclear and important to define whether peri-urban informal settlements are considered as urban or rural areas and perhaps not even included in the sampling. The potential influence of the definition of urban and rural areas may have an impact on estimates especially if the definition was revised over time. It is not possible to compare the trends with the population growth and movement as most of the explanatory variables – regions, area, wealth quintiles - used in this analysis were also used to ensure representativeness of the sample at the study design stage.

Recommendations

Findings from this study are explanatory and were subject to data availability. Further analysis using additional data sources and more exhaustive indicators and disaggregation factors would be necessary to direct interventions and efforts towards the groups of the population that are still left behind. It is clear that resources should be directed to those who lack minimum access to water and sanitation. In Malawi, such people are mostly found to be in the poorest rural Central and Southern areas.

In view of SDGs, future surveys and studies should include indicators that address safely managed drinking water and sanitation services. A MICS survey along with a water quality module is currently underway in Malawi. The introduction of the first estimates of safely managed drinking water services for the country will likely improve the accuracy of national estimates.

Conclusions

Progress was made to improve access to drinking water and sanitation in Malawi for all parts of the population as measured by areas, regions, wealth and education. Overall, the proportion of the population without access to an improved drinking water source within

30 minutes and/or practising open defecation was more than halved between 1992 and 2017.

The analysis identified the most vulnerable parts of the population (as measured by having limited access and practicing open defecation) as being poorest rural populations living in Central and Southern Malawi. Emerging trends on progress and inequalities in water supply and sanitation services show that efforts should be put towards improving access to basic services in the most vulnerable populations across all geographic and socio-economic groups of the population. Drawing attention to the people being left behind without at least basic access to water and sanitation service is necessary to reduce the gap within the population and ensure equitable access water and sanitation for all by 2030 with respect to SDG's agenda.

Conflict of Interest

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

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Chapter 3

Manuscript Title:

Evaluating self-reported measures and alternatives to monitor access to drinking water: Evidence from a case study in Malawi

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Author Contributions:

AC lead conceptualization, design and implementation of the analysis with the supervision of CD, ET, and EOW. AC analyzed the results and wrote the manuscript. All authors commented and contributed to the final version of this manuscript.

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Abstract

Monitoring access to drinking water is complex, especially in settings where on premises water supply is not available. Although self-reported data are generally used to estimate coverage of access, the relationship between self-reported time travelled and true time travelled is not well known in the context of water fetching. Further, water fetching is likely to impact the quantity and quality of water a household uses, but the data supporting this relationship is not well documented. The objective of this cross-sectional study was to appraise the validity and reliability of self-reported measurements used to estimate access coverage. A case study was conducted in Southern Malawi to enhance understanding of the measures available to assess and monitor access to drinking water in view of generating global estimates. Self-reported data were compared with objective observations and direct measurements of water quantity, quality and accessibility. Findings from this study highlight the variations between different measures such as self-reported and recorded collection time and raise awareness with regard to the use of self-reported data in the context of fetching water. Alternatives to self-reported indicators such as GPS-based or direct observations could be considered in surveys in view of improving data accuracy and global estimates.

Keywords

Drinking water | Self-reported | Accessibility | Water Quality | Water Quantity

Introduction

A target of universal and equitable access to safe and affordable drinking water for all by 2030 was established with the Sustainable Development Goals (SDGs) of the United Nations (WHO/UNICEF 2017a). This target builds on the previous Millennium Development Goals (MDGs) target to half by 2015 the proportion of people without sustainable access to safe drinking water.

As part of the 2030 Agenda, an important adjustment to the global indicator used by the WHO/UNICEF Joint Monitoring Programme for Water Supply (JMP) to produce estimates regarding access to drinking water was made. Instead of the population using an "improved" water source (i.e., which by nature of their design and construction, have the potential to deliver safe water) which only referred to the source technology, as used in the MDGs, the population using "safely managed drinking water services" was set as the improved indicator used to monitor progress towards the new SDGs (WHO/UNICEF 2017a). The improved indicator refers to drinking water from an improved water source that is located on premises, available when needed and free from faecal and priority chemical contamination. The need for an inclusive and meaningful indicator was previously raised as the omission of factors such as accessibility, quantity, (Cassivi et al. 2018b, Devi and Bostoen 2009), quality or seasonality (Bain et al. 2012b, Onda et al. 2012) was said to result in an overestimation of the population with sustainable access to drinking water as targeted.

In 2017, the JMP estimated that 2.1 billion people were lacking access to safely managed drinking water. It was reported that 0.8 billion people had no access to an improved water source within 30 minutes, among which 0.7 billion were using unimproved water sources or surface water as reported at the end of the MDG (WHO/UNICEF 2017a). Locations/households where there are no on-premises piped connections or sources are particularly exposed to challenges related to water fetching: reliability of a water source and its distance to a household are likely to influence how much water is collected (White et al. 1972, WHO/UNICEF 2017a). Aside from the actual distance between the source of water and the point of use, individual behaviours and environmental effects may have an impact on the water source that consumers choose to access, which in turn influences the quantity and quality of water collected (Cassivi et al. 2019, Esrey et al. 1991, White et al. 1972) and thus influence overall access to water.

The integration of water accessibility, quantity and quality components in the SDG indicators of access indeed resulted in a reduction of the baseline proportion of the population considered as having access to water in comparison with MDGs end line. It is expected that such adjustment will increase the accuracy of the indicator for generating global estimates in the next years (WHO/UNICEF 2018), but it represents an important challenge in terms of data availability and reliability. Collecting data and monitoring access to water worldwide is complex, especially when different factors such as accessibility, availability, quality and quantity should to be measured and included in a multifaceted definition of access to water services. Using comprehensive and comparable metrics is essential to ensure data availability globally (Alhassan and Kwakwa 2014, Arouna and Dabbert 2010, Cairncross and Cliff 1987, Mertens et al. 1990). However, establishing and implementing such measures remain challenging as it increases demands on international and national systems and agencies (Bartram et al. 2014, Cassivi et al. 2019, Schwemlein et al. 2016).

Many current estimates for water access in low- and middle-income countries are based on national household surveys (Bain et al. 2012b, Bartram et al. 2005) which, though comprehensive, have some important limitations. Self-reported estimates including the type of water source and the time needed to collect water may be incomplete and unreliable (WHO/UNICEF 2018). As a result, there are generally no indicators or verified measurements included in surveys (e.g., national household surveys) to portray access in households where water on premises isn't available.

The potential for including observations and direct measurements in accessibility studies is apparent. Methods such as Global Positioning System (GPS) based measurements (e.g., coordinates, tracking devices, proximity analysis) and direct observations need to be explored further as they may reduce bias associated to self-reporting measures of access and increase data reliability (Bartram et al. 2014, Ho et al. 2014, Pearson 2016, Ramesh et al. 2015). Previous metrics were limited by technology availability (e.g., water quality testing, electronic devices), but such application is becoming more commonly available

(Crow et al. 2013, Jimènez and Pèrez-Foguet 2008, Ntozini et al. 2015, Pearson 2016, Tamason et al. 2016).

Exploring and comparing alternatives to self-reported measures are necessary in order to contribute to strengthening global estimations and improving our understanding of access to drinking water. Improved measures will help ensuring suitable use of data for programming water-related interventions and targeting appropriate responses to needs in view of increasing water security and equity, reducing the burden of fetching water and preventing water-related infectious diseases associated to lack of access. Such research is essential if we are to reach universal and equitable access to safe and affordable drinking water for all by 2030 as set in the SDG target 6.1 (Cronin et al. 2017, WHO/UNICEF 2017a). Better measures could lead to better estimates and results.

The objective of this study was to enhance understanding of the measures available to assess and monitor access to drinking water. More specifically, this study assessed the validity and reliability of self-reported measurements to estimate access coverage.

Materials and Methods

Study Design

This cross-sectional case study used data collected in March and April 2019 at the end of the rainy season in Southern Malawi. The sample comprised a total of 375 households not served by piped water supply into dwelling and located in selected areas (5% margin of error at the 95% confidence level). Households were randomly selected in three sites of different population density located in the Southern Region, i.e., Ndirande (peri-urban), Mbayani (peri-urban) and Chikwawa (rural). The sites were selected through local partner guidance and local community and authority approval.

Households were recruited through a voluntary participation process, and free and informed consent was obtained from all participants' households. Sampling was based on the commonly used WHO EPI-sampling method for low-income countries (WHO/UNICEF 2017a): In each site, enumerators walked in pairs starting from equidistant and centrally located water sources, along opposite directions which were randomly determined by spinning a bottle. Households were selected according to a sampling interval (i.e., 10^{th} – 5^{th} – 2^{nd} closest right-handed house) which was determined based on the sites' densities. Participating households were visited once by a local enumerator for a duration of approximately 1 hour including walking to the main water source. Methods and measures used in this study were selected as they are easily replicable and time and cost-effective in settings where resources are limited.

This research was approved by the National Committee on Research in the Social Sciences and Humanities (NCRSH) (P.10/18/326) in Malawi and the Human Research Ethics Board at the University of Victoria (18-1129). Local enumerators fluent in Chichewa and English were hired and trained for data collection in the field including for applying structured questionnaires, recording observations and conducting water quality testing.

Structured Questionnaire

A structured questionnaire which relates to the household's characteristics and perceptions; water, sanitation and hygiene behaviours; and health and drinking water supply was administered (Annexe A). The questionnaire applied by the enumerators has been based and adapted from established and readily available UNICEF Multiple Indicator Cluster Surveys (MICS) and Water Quality Module (https://mics.unicef.org). Additional elements such as observations, measurements, recording of images/photos and coordinates were included in the questionnaire and carried out by the enumerators.

Questionnaires were double (also known as back) translated to ensure accuracy and applied in local language. The adult household member most likely to be knowledgeable about households drinking water accessibility was selected for the interview. In cases where the primary water fetcher wasn't available, the interview was conducted with the head of the household. KoBo Toolbox (https://kobotoolbox.org) was used on Samsung Galaxy tablets for data collection.

GPS-Based Measurements

Coordinates of each household were recorded when visited by the enumerators using the tablets. Household members were also asked to walk with the enumerator from the household to the water source from which they usually collect water using the usual path, where coordinates were also recorded. The coordinates were saved along with current time (hh:mm:ss) when the enumerator left the household and arrived at the water source. Coordinates were subject to 4-meter accuracy provided by the tablet. Household and water source coordinates were paired to study paths and Euclidean distance ("as the crow flies") between both points. Google Earth Pro and ArcGIS were utilized for spatial analysis using geolocations. Coordinates and metric units were used (WSG84) for analysis. The distance from each household to their reported water source was estimated using proximity analysis. Recorded time between household and water source was calculated using the difference from the departure time to arrival time captured between the households and the water sources.

Water Quality Testing

Portable membrane filtration kits were used for water quality testing at the point of collection (i.e., water source sampling) and at the point of use (i.e., household drinking water sampling). The methods used were based on readily established MICS guidelines and procedures for water quality testing (Bostoen and Chalabi 2006, Khan et al. 2017, Milligan et al. 2004, WHO 1991). Household members were asked to provide a cup of water from which a sample was collected. Household drinking water sampling and testing was completed within all the selected households (n=375). Household members were asked to walk with the enumerator to the water source from which water from the cup was withdrawn (or generally withdrawn, in case where multiple sources were used), and a sample of water was collected at the water source. No additional samples were collected in cases where the enumerator had already tested the same source on the same day. A total of 192 water sources, corresponding to 289 reported household water sources, were functional and thus tested. Each sample of 100 ml of water was tested for *E. coli* directly on site using a portable membrane filtration kit. Blank tests were performed daily by the enumerators to ensure consistency and data reliability. The plates (Compact Dry™ EC) were incubated at body temperature (approximately 37 ºC) using incubation belts (i.e., same used for MICS surveys) during the day while fieldwork was being conducted and in a laboratory incubator (University of Malawi) at 37 ºC to complete the total incubation time of at least 24 hours. *E. coli* was enumerated by an experienced researcher in the laboratory. The samples' microbial quality was classified by the *a priori* waterborne risk categories (Lloyd et al. 1991): very low (< 1 cfu/100 ml); low (1-10 cfu/100 ml); moderate (11-100 cfu/100 ml) and high (>100 cfu/100 ml).

Study Variables and Measures

Data collected were compiled and reported for each participant household. Each measure and study variables were assessed and compared against the other measure with regard to the type of measurements: self-reported by the participant, objectively observed (by an enumerator or researcher) and directly measured (e.g., water quality testing). Each variable was subsequently classified in the following groups to allow comparison and evaluate consistency (Table 3.1). Each variable was compared to its equivalence:

Table 3.1. Variables and comparable measures included in the analysis.

	Self-reported measures	**Other measures or observations**
Water sources	Self-reported sources of water used by members of the household.	Type of sources identified on a picture taken by the enumerator.
Water quantity	Quantity of water collected daily Quantity of water collected each trip*frequency	
Water quality	Perception of the quality of water sampled in the household	Microbial water quality of the water tested in the household Microbial water quality of the water testing at the water source
Water accessibility	Self-reported collection time (minutes) between household and water source. Estimated distance (meters) between household and water source as reported by enumerators	Walking time (minutes) recorded between household and water source. Euclidean distance (meters) measured with GPS coordinates of the household and the water source

Data Analysis

Data were analysed using Stata SE14. Descriptive analysis including measures of frequency, central tendency and dispersion (i.e., standard deviation (SD), confidence intervals (CI)) and appropriate statistical hypothesis testing were conducted to compare measurements of access. Fisher's exact test was used to assess relationship between categorical variables and explanatory variables (i.e., household size, type of water source, household perceptions, water quality), as expected values for water quality resulted in fewer than 5. Tests of normality were conducted on continuous variables including quantity and accessibility measurements, and the assumption of normality was rejected. As a result, Wilcoxon signed-rank test and Spearman's rank correlation (r_s) were used to compare groups and measure the degree of association between continuous variables. P-value thresholds for statistical significance were reported when an association was found at the

95% confidence interval. Missing values were excluded from analysis. In order to ensure representativeness of this study and respect self-reported measures as declared by participants, no extreme values or potential outliers were excluded from analysis. Results presented were rounded off to the closest unit after analysis to ease readability and interpretation when necessary.

Results

Descriptive Characteristics

Household size varied between 1 and 19 individuals with an average and median of 5 people per household. Most respondents were aged under 40 years old (77%) and were women (89%). Education level of the respondent varied as follows: no education (8%); primary (51%), secondary (38%) or higher (3%).

Water Sources

Among all households (n = 375), one third (35.5%) reported only using a single (primary) water source throughout the year. Most households (64.5%) reported using multiple sources water sources (> 1) throughout the year, among which, respectively, 48%, and 16.5% reported using two or three sources. In terms of distance, most of the households (83%) reported that the primary source was the one closest to their dwelling. Self-reported results for households using multiple sources (n = 242) showed that most of the primary sources reported as the closest were also located within the shortest reported walk time (61%) or within an equal walking time from the other sources (16%). Among the remaining households, the shortest reported collection time corresponded to the second (21%) or the third source (2%).

The reported and observed type of water source did not always match. In nearly all of the households (94%), the drinking water source visited during the interview was the same type as the one reported as the primary water source used by the household. Following identification of the water source from the picture taken during sampling visit (n = 296), the type of water source as reported by household members corresponded to the identified type of source for most households (86.5%). Of those that did not correspond (13.5%), the differences observed can be grouped as follows: public tap/standpipe versus water kiosks (9.1%); piped to yard or to neighbour versus public tap (i.e., standpost, standpipe) (3.7%)

and; tap versus boreholes (0.7%). Of the ones reporting using a water kiosk or a water tap (38%), most households (93%) also reported paying for the water. Additionally, all households reporting using a public tap (though really a water kiosk) reported paying for the water. For one third of the households (32%), the water sources were not functional during the enumerators' visit. Results, however, indicate that most of these households (93%) previously reported that water was available from this source throughout the year.

Water Quantity and Storage

The total daily quantity of water collected as reported by household members ranged from 0 to 980 litres (M = 186, SD = 124) (Table 3.2). The quantity of water was positively correlated with household size ($r_s = 0.3049$; $p < 0.001$). The quantity of water collected per capita ranged from 0 to 400 litres with an average of 41 litres per capita on a daily basis. In contrast, the calculated daily quantities based on household's reported trip frequencies ranged from 1 to 80 trips per day (M = 6, SD = 5) and reported quantity of 56 litres collected per trip ranged from 0 litres to 500 litres (M = *56,* SD = 52) with an estimated total average ranging from 0 of 6400 litres per day (SD = 533). The estimated quantity of water per capita ranged from 0 to 1600 (M = 73. SD = 118), which is considerably greater than the daily reported average.

Direct daily quantity reported was lower than the estimated daily quantity based on trip frequency with a mean difference between the two of 147 litres (SD = 523), 95% CI [94, 200 litres]. Wilcoxon signed-rank test revealed a statistically significant difference between direct daily self-reported quantity and estimated quantity based on trip frequency both using individual and average collected quantity ($p < 0.001$). Household members reported using between 0 and 100 containers each time they collect water (M = 4, SD = 3)). The 95th percentile was measured as 8 containers and the median as 7 containers; the larger values can be considered outliers.

Table 3.2. Variations in measures of self-reported quantity of water collected in households.

Measures		n	(unit)	Range	Mean	Median	Std. Dev
Quantity of water collected	Total quantity reported daily	375	(L/household)	0-980	186	160	124
			(L/capita)	0-400	42	33	36
	Trip frequency * quantity/trip	375	(L/household)	0-6400	333	225	533
			(L/capita)	0-1600	73	47	118
	Trip frequency * avg. quantity/trip	375	(L/household)	56-4480	330	280	274
			(L/capita)	7-1120	75	56	72
Other measures	Trip frequency	375	(trip)	1-80	6	5	5
	Quantity of water	375	(L/trip)	0-500	56	40	52
	Number of containers	375	(total/trip)	0-100	4	7	3

The type of storage, as reported by household members (i.e., jerrycans, covered or uncovered buckets, pots, metal containers, drums), was compared to the type of storage observed and recorded by the enumerator conducting surveys (n = 296). Most households (86%) were observed to use a container corresponding to the one they self-reported. The remaining households (13%) were observed to use a storage container different to what they reported using in the questionnaire. Of those, half (7%) reported using a covered container or a jerrycan, but were observed using an uncovered container.

Water Quality

For drinking water quality, nearly half of participant households (43%) reported that perceived water safety was the most important characteristic for water consumption over aesthetic characteristics like colour, odour and taste. Water quality was self-reported as being excellent in most households (65%), fair/neutral in nearly one third (30%) of households and poor in few households (4.5%). Results from *E. coli* enumeration of water samples were classified in the following categories: very low risk (15%); low risk (24%); moderate risk (34%); and high risk (26%). A comparison of both perception and the measured level of risk was made with the following associations: excellent quality was associated with very low risk water; fair and neutral quality corresponded to low and moderate risk and; poor quality was defined as using high risk water. A difference was determined between a household's perceived water safety and the measured microbial water quality of the cup of water they provided. Self-reported water quality was identified as being the same as measured water quality from the cup (28%), overestimated (64%) (i.e., perceived quality was greater than measured quality) or underestimated (8%) (i.e., perceived quality was lower than measured quality) (Table 3.4). Using Fisher's exact test, no significant association was, however, found between the microbial water quality of the cup and household perception (p = 0.38). A significant association was, however, found between household perception and measured microbial water quality at the water source ($p < 0.05$) (Table 3.4).

Table 3.3. Comparison between households' members' perception of water and measured microbial water quality of the sample taken from the cup (%).

		Microbial water quality : Level of risk at the point of consumption									
		Very low		Low		Moderate		High		Total	
		%	n	%	n	%	n	%	n	%	n
Perception water quality	Excellent	10%	37	18%	66	22%	80	16%	58	65%	241
	Fair - Neutral	5%	18	6%	22	11%	40	9%	34	31%	114
	Poor	0%	1	1%	2	2%	8	2%	6	5%	17
	Total	15%	56	24%	90	34%	128	26%	128	100%	372

Table 3.4. Comparison between households' members' perception of water and measured microbial water quality of the sample taken from the cup and the water source (%).

		Microbial water quality : Level of risk at the point of collection									
		Very low		Low		Moderate		High		Total	
		%	n	%	n	%	n	%	n	%	n
Perception water quality	Excellent	42%	121	11%	31	6%	16	3%	10	62%	178
	Fair - Neutral	16%	46	9%	25	3%	10	4%	13	33%	94
	Poor	3%	9	1%	4	0%	1	1%	3	6%	17
	Total	61%	176	21%	60	9%	27	9%	26	100%	289

Self-reported perception of the quality of water collected by households' members was consistent with the actual measured microbial water quality of the source more than half (55%) of the households. Among those that were consistent, three quarters reported excellent quality and were in fact using a source that was free from contamination (0 cfu/100 ml). Perceived water quality was overestimated by the household in one quarter (

24%) of the households when compared to the microbial quality of the water source, which is lower than the comparison with the cup of water, or underestimated in comparison to the measured quality of their primary source of water (20%).

Respondents were asked whether anything was done to make the water that is served in the cup, safer to drink. Some kind of treatment was used in few households (9%), where the majority (91%) reported using bleach or chlorine. The use of a water treatment method wasn't associated to the microbial quality of the water in the cup (p = 0.06) nor the perception of water quality in the household (p = 0.11). Households not treating their water said it was because the water is already clean (85%) and/or a treatment is too expensive (13%). Many households reported not using any treatment because they consider the water to be already clean which was significantly associated with their perceptions of the sample of water collected for water quality testing ($p < 0.001$). No significant association with reporting that water was already clean was observed with microbial quality of the water sampled in the cup (p = 0.49) or at the source (p = 0.25).

Overall, a significant association was observed between microbial water quality from the water source and the cup ($p < 0.001$) (.

Table 3.5). Results demonstrated that the level of risk generally increased (67%), remained the same (28%) or was improved (5%) in from the source to the cup. Improvement in water quality wasn't found to be significantly associated to the use of a treatment (p = 0.97).

Table 3.5. Comparison of microbial water quality from the water source to the cup of water that member of the household would drink (%).

Level of risk		Point of consumption (water cup)			
		Very low	Low	Moderate	High
Point of collection (water source)	Very low	32%	51%	57%	34%
	Low	4%	14%	24%	18%
	Moderate	1%	6%	12%	8%
	High	2%	0%	2%	22%

Water Accessibility

Accessibility to water was assessed with one-way time and distance measurements (Table 3.6). The self-reported collection time ranged from 0.5 to 75 minutes (M = 6, SD = 8). Collection time was similar in urban and rural areas with an average of 5.7 minutes in urban areas and 6.7 minutes in rural areas, and the highest collection time was reported in the urban area with the greatest density. The recorded time, measured with a timer, while travelling from the households to the water source ranged from less than 1 minute to 13 minutes for a one-way trip (M = 2.5, SD = 2). The recorded time was similar in urban and rural sites with the average being 2.2 minutes in urban areas and 2.9 minutes in rural areas. A difference was, however, observed between areas in terms of the distance measured with geographic coordinates. With one-way distances measured with the coordinates ranging from 2 m to 434 m (M = 69, SD = 75), the average distance was 37 m in urban areas and 115 m in rural areas. However, as with the collection time, the greatest distance from the household to the source (i.e., 434 m) was observed in the urban area with the greatest density. The distance reported by enumerators was similar to the Euclidean distance with a range from 1 to 500 m (M = 77, SD = 108). The average reported distance was 40 m in urban areas and 141 m in rural areas.

With regard to reported measures, some inconsistencies were observed with the self-reported time to collect water and queue time. The queuing time was reported as being longer than the total round-trip time (including queue time) in one quarter (26%) of households. Only households reporting a shorter queuing time with respect to their total round trip collection time were included for further analysis (i.e., negative values were excluded).

Table 3.6. Variations in collection time (minutes) and walking distance (meters) measures.

Measure	Measurement	n	(unit)*	Range	Mean	Median	Std. Dev
Estimated walking time	Self-reported (households)	276	(minutes)	0.5-75	6	2.5	8
			(meters)	*14-2085*	*173*	*70*	*224*
Recorded time	Timer	363	(minutes)	0-13	3	2	2
			(meters)	*0-379*	*74*	*58*	*66*
Euclidean distance *(i.e., Straight-line)*	Geographic coordinates	339	(meters)	2-434	69	40	75
			(minutes)	*0.2-36*	*6*	*3*	*6*
Estimated distance	Reported by enumerators	363	(meters)	1-500	77	25	108
			(minutes)	*0.13-63*	*10*	*3*	*14*

**Average walking speed with respect to Euclidean distance was used to estimate corresponding time or distance unit measurements (recorded time = 1.75 km/h; self-reported collection time = 1.67 km/h)*

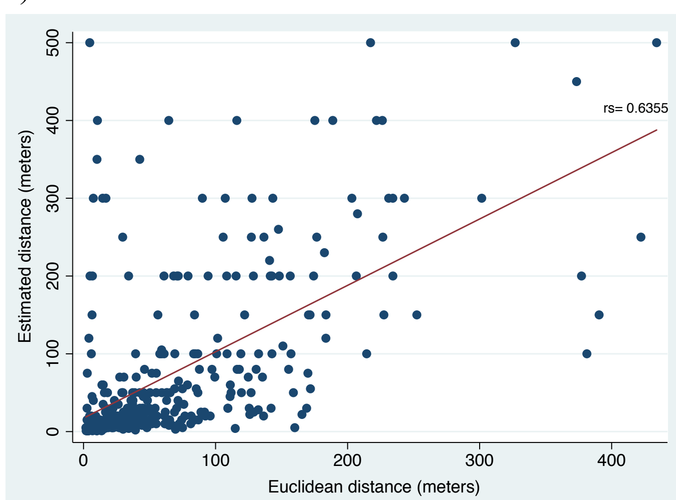
Summary statistics show wide variations and ranges for collection times and walking distances. Results show that the greatest deviations were observed for self-reported measures such as estimated distance and self-reported collection time. Correlation analysis showed positive associations between the variables and demonstrated that the strength of the relationships is subject to important variations (Figure 3.1).

	Estimated distance (enumerators)	Euclidean distance (GPS coordinates)	Recorded walking time	Self-reported collection time
Self-reported collection time	0.4441 *p < 0.001*	0.2881 *p <0.001*	0.3849 *p < 0.001*	
Recorded walking time from the household to the source	0.5470 *p <0.001*	0.5647 *p <0.001*		
Euclidean distance measured with GPS coordinates	0.6355 *p <0.001*			
Estimated distance reported by enumerators				

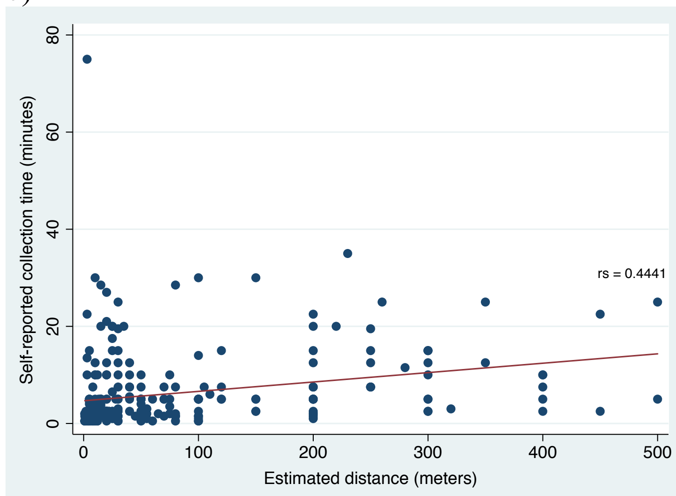
Figure 3.1. Correlation between water accessibility measurements (Spearman's rank correlation coefficient, statistical significance).

The strongest association between the water accessibility measurements was observed between Euclidean distance measured with geographic coordinates and distance estimated as reported by the enumerators (Figure 3.2.a). Spearman's correlation shows a statistically significant positive correlation between both variables ($r_s = 0.6355$; $p < 0.001$). One-way walk time between households and water sources, recorded with a timer by the enumerators, was also strongly associated with Euclidean distance ($r_s = 0.5647$; $p < 0.001$). Self-reported collection time, as reported by the participants, was weakly associated to the other measurements (i.e., Euclidean distance, estimated distance and recorded time) as opposed to direct measurements. Only self-reported collection time (i.e., one-way without queue time) and estimated distance reported by the enumerators were significantly associated ($r_s = 0.4441$; $p < 0.001$) (Figure 3.2.b). Self-reported collection time and Euclidean distance were also significantly correlated, although the strength of the association was the lowest ($r_s = 0.2881$; $p < 0.001$) (Figure 3.2.c).

a)



b)



c)

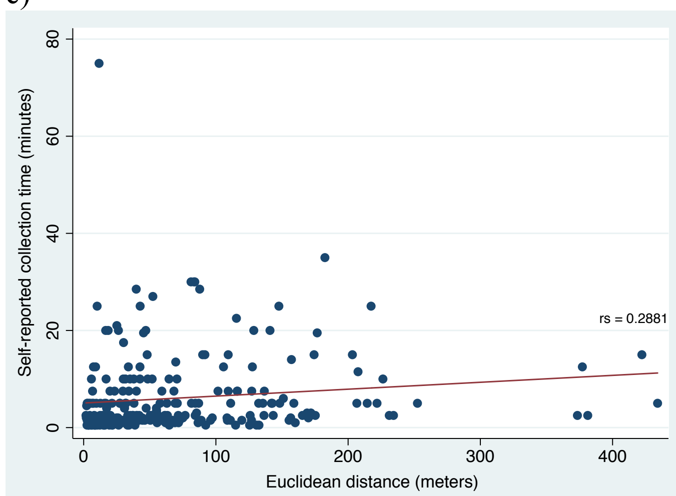


Figure 3.2. **a)** Linear correlation between Euclidean distance and estimated distance as reported by the enumerators; **b)** Linear correlation between self-reported collection time and estimated distance as reported by enumerators; **c)** Linear correlation between self-reported collection time and estimated distance as reported by enumerators.

Discussion

Water Sources

The type of water source reported by respondents was found to be a valid indicator to assess coverage. Self-reported measures indicate that household members can reliably identify the type of water sources they are using and this is likely a function of the translation effectiveness. Results reveal that the lowest reported time to collect water was correlated to the source they reported being the closest. The small difference observed between the self-reported and observed type of source is likely attributable to the wording used to describe the water supply design. Results show that the difference between the reported type of water source could be explained by the perception of what is considered as a personal, neighbourhood or public responsibility. Most sources reported as water kiosks and identified as a public tap were unofficially named and labelled by communities as water kiosks (i.e., drawing and writing on the wall of the public tap). As per the JMP definition of water sources, a water kiosk would refer to a water point that sells water at a price, whereas a public tap would be located in a public space and not require payment (WHO/UNICEF 2017b). The key operational difference between both types of sources would be attributable to the cost of use, although water kiosks may have the same design features as standpipes or public stand post. More households reported paying for water in peri-urban areas where piped water might be provided, compared to rural areas which mostly rely on boreholes and this is consistent with previous findings (UNICEF/WHO 2018). The results highlight the importance of accounting for water affordability and considering cost of water in monitoring access as recommended in previous studies (Adams and Smiley 2018, Bartram et al. 2014, Clasen 2016, Kayser et al. 2013). A particular attention should also be held to water source functionality and continuity as water was not functional although households initially reported water being available throughout the year. It may be that there are intermittent times when the water does not run, but that the water runs most days and doesn't stop for sustained periods. Introducing such measures would be valuable to increase reliability of self-reported measures to generate large scale estimates.

Water Quantity

Overall, the average quantity of water reported in households– from 42 litres to 75 litres per capita - is shown to be greater than the average quantity of water reported in studies conducted in the last decade in other sub-Saharan countries (Alhassan and Kwakwa 2014, Mahande et al. 2012, Martinez-Santos 2017, Sakisaka et al. 2015) but this couldn't be compared to national estimates as such metrics haven't been reported. A significant difference was however, observed between the total quantity of water collected as reported by respondents and total the quantity of water calculated using trip frequency and the quantity of water collected each trip. The total quantity of water directly reported was lower than the one calculated using proxy variables (i.e. trip frequency and quantity). Results highlight some inconsistency (e.g., fetching water 100 times per day; carrying 80 containers each trip) in data reported by households which most likely lead to an overestimation of the calculated quantity of water collected in some cases. Such data were, however, kept in the analysis to conduct realistic estimates with respect to self-reported data. Misreporting issues related to self-reported measures were highlighted in a case study conducted in South Africa where people reported collecting a smaller quantity of water although distance was being improved following an improvement in water supply (Jagals 2006).

A correlation has been reported between the number of household members and quantity of water collected and used by households in multiple studies (Hadjer et al. 2005, Hoque et al. 1989). As such, estimating quantity of water collected per individual would allow to control for household size and thus better assess water security within households.

Without direct measures of the quantity of water collected and used in households it is not possible to assess the validity and reliability of self-reported measure for water quantity. Multiple studies used self-reported measurement or observations to measure the quantity of water collected or used in households but important inconsistencies across studies have been highlighted previously in a systematic review (Cassivi et al. 2019). The possibility and cost implications of using a water metering system on-site should be investigated further in order to avoid the nuisance attributable to the presence of an enumerator observing families during the day. Following a cross-sectional study conducted in Malawi, Masangwi et al. (2010) suggested using longitudinal studies to better understand household behaviour and related effect of water quantity and quality.

Self-reported storage was found to be similar to the type of storage observed by the enumerators. Results, however, demonstrated that some households misleadingly reported using a container that was covered when it was found not to be. Over-reporting favourable behaviour demonstrates a social desirability bias which has been well documented in other water, sanitation and hygiene studies in developing countries (Murphy et al. 2016, Null and Lantagne 2012, Park et al. 2016).

Water Quality

Microbial water quality at the source was significantly different than that measured in the cup of water provided at the household. Results show that the quality of water generally deteriorates between the two stages of collection resulting in an increased level of risk, which is consistent with other studies (Harris et al. 2013, Leiter et al. 2013, Shaheed et al. 2014, Wright et al. 2004a).

The association between water quality perception and the actual microbial quality at the water source (and not the cup of water) highlights the fact that respondents may rely on the perceived quality of the water at the point of collection. A respondent's perception of the sampled water quality was shown to be associated to the source water quality, but was not associated to the quality of the water in the cup at the point of consumption. Water quality at the household was overestimated in most households which is consistent with results from a study conducted in peri-urban Cambodia (Onjala et al. 2014, Orgill et al. 2013). Although the potential remains understudied, such results demonstrate that household perception could be a reliable indicator for microbial quality only at the first stage of collection but shouldn't be used as a general indicator of quality. As such, most households reported not treating the water at the point of use because they considered that the water is already clean; indeed, most water sources were found to be free from contamination (<1 cfu/100 ml). The impact of the cost of water treatment methods on household practices should also be explored further as this was reported as being a barrier for treating water at the point of use, and this was consistently found in other studies (Freeman et al. 2009, Ram et al. 2007, Wood et al. 2012).

The importance of considering households' decision-making related to water sources has also been highlighted in a cross-sectional study conducted in rural Malawi (Smiley 2017). The use of household perceptions to monitor access to water is worth exploring in upcoming studies.

Previous studies demonstrated that the false sense of protection associated to households perceiving water as clean and thus potential recontamination, was a risk factor for diarrheal diseases and health (Banda et al. 2007, Francis et al. 2015, Leiter et al. 2013, Rufener et al. 2010). Results from a case study conducted in Ghana demonstrated that the majority of respondents who perceived their water as unsafe also reported treating the water before using it (Alhassan and Kwakwa 2014). Although perception of the quality at the water source is shown to be an important factor for water handling, post-supply behaviours and collection mechanisms should prevent water contamination. Careful attention should be put towards ensuring that water quality is maintained at all stages of water collection particularly at the point of use. Findings from this study further highlight the needs to emphasise the promotion of hygienic water collection and the use of drinking water treatment at the point of consumption even if source quality and household perception is relatively good. Educational and informational campaigns should be used to emphasise the fact that water quality cannot always be assessed visually (Orgill et al. 2013)

Water Accessibility

The average one-way collection time was reported or measured below ten minutes and the average distance was below 200 metres for all measures. Our results are consistent with other studies based on surveys conducted in Malawi which found that collection time was generally lower than 30 minutes round-trip indicating that at least basic access to water is provided in most households (Cassivi et al. 2020b)

Estimates, however, generally varied between the different measures of time and distance used in this study. Among all measures, Euclidean distance was found to be the most comprehensive and reliable indicator when compared with the others. Euclidean distance was strongly correlated to the distance as reported by the enumerators and to the time recorded between the household and water source. A moderate correlation was also observed between the distance estimated by the enumerators and the time recorded. The difference between recorded time and measured distance is likely explained by the fact that households' members use more direct path (i.e., with shortcuts) as opposed to straight line roads to travel from their household to the water source. Results from a previous study, however, demonstrated that straight-line distance was a good proxy for route distance (Davis et al. 2012, Ho et al. 2014). If tablets, using coordinates or recording the time between the house and the water source would be easily applicable in the context of national household surveys including a water quality module (i.e., water quality testing at the household and water source). Such an application would be time and cost efficient as it wouldn't require additional resources for surveying. Although promising, the application of such measures is currently limited. No international indicator allowing for a standardized water point mapping methodology to estimate coverage of access is yet available, although previously recommended (Jimènez and Pèrez-Foguet 2008).

Self-reported collection time, monitored in national household surveys (e.g. DHS, MICS) and used by JMP to estimate global coverage of access, was the least consistent and reliable indicator when compared to direct measurement and others reported measure. Weak correlations were found between self-reported collection and recorded time along with estimated distance. This is consistent with findings from other studies conducted in Sub-Saharan Africa which found that self-reported collection time was generally overestimated compared to GPS based measurements (Crow et al. 2013, Ho et al. 2014). A poor correlation between self-reported collection time and GPS measurements has been highlighted (Adams 2018, Bartram et al. 2014, Clasen 2016) and the use of self-reported measures to estimate collection time has been reported as a limitation in multiple high-impact studies (Devi and Bostoen 2009, Graham et al. 2016).

Additionally, results demonstrated that queue time is an ambiguous measure that should be integrated with caution because respondent may have difficulties to recall actual walking and distinct waiting time. Previous studies also showed that queuing time could reach several hours and in cases, considerably greater than actual walking time (Arouna and Dabbert 2010, Cairncross and Cliff 1987). Ho et al. (2014) hypothesized that the overall reported collection time may be conflated by queuing time and walking time, which reduced a respondent's ability to estimate actual fetching time. A careful attention should be held to the use of queuing time as an indicator considering it may imply other social implications (Sorenson et al. 2011). As such, the use of one-way collection time along with a separate average queue time measure is recommended to improve validity of the reported time measure.

Limitations

Findings from this study aimed to enhance understanding of the methods used to monitor access. Although results from the analysis are valid and expected to be replicable, it is possible that the magnitude of the effect would vary in different settings. Conditions where water sources are located farther in terms of time/distance or where water security is compromised by drought may influence respondents' behaviours and perceptions. Findings may not be generalizable and recommendations should be tested for relevance and validated in other countries and various settings before being integrated in large scale household surveys. Additionally, water accessibility measurements were assessed using one-way collection time or distance, and the exactitude may be limited by queue time. Self-reported collection time was collected as a round-trip measure from which queue time was removed. Further studies should aim to assess the magnitude of the impact of queue time on round-trip water collection. Considering the explanatory nature of the water quality module, only one sample was tested from each sampling point (i.e. no replicates) which may not be representative of overall quality of water. Also, it is not certain that water sampled at the point of collection was collected at the same water source where the sample was taken, multiple water sources could have been used to fill the storage container and this could have been done at different times. Although a higher number of positive blanks than expected were found, the impact on the measured risk classification was considered inconsequential as the results would bias the values upwards and result in an overestimation of water quality.

Conclusions

Results from this study highlight the importance of considering the use of alternatives to self-reported measures in order to improve the accuracy of estimates. As such, generating global indicators and promoting standardized methods and measures to estimate access in small- and large-scale household surveys would be valuable. Additionally, particular attention should be paid towards households' perceptions and behaviour in accessing water supply. This will help identifying appropriate interventions to improve overall access to water (i.e., accessibility, quantity and quality). It is essential to move beyond the "improved water source" indicator for accessible and safe drinking quality which may yield a false sense of protection for households.

Methods used in this study were shown to be easy to implement and replicate for measuring water accessibility, quantity and quality. Future research should aim to explore the potential of using metric devices and observations to measure quantity of water collected and stored in households and assess the extent of post collection contamination between water sources and households. Ongoing work will further allow us to identify the stages of contamination by comparing observations and self-reported measures at each point of water collection.

Chapter 4

Manuscript Title:

Drinking water accessibility and post collection contamination: A seasonal cohort study in Malawi

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AC lead conceptualization, design and implementation of the analysis with the supervision of CD, ET, and EOW. AC analyzed the results and wrote the manuscript. All authors commented and contributed to the final version of this manuscript.

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Abstract

Background: Lack of access to safe drinking water on premises remains widespread in low- and middle-income countries. Interventions to improve access to safe water at the point of collection are essential, but water safety at the point of use remains of important consideration. This research aimed to improve understanding of households' behaviours in collecting water with regard to seasonality and to further identify stages of collection where post-collection contamination occurs.

Methods: A seasonal cohort study, including 115 households, was conducted in Malawi. Along with household surveys and observations, samples of water were tested for microbial water quality at four different stages of water collection: water sources (S1), collection container (S2), storage container (S3), cup of drinking water (S4). The level of risk using *E. coli* as an indicator of contamination (cfu/100 ml) was used to assess the impact of post-collection contamination.

Results: The results indicate that most water sources were free from contamination and this was proportionally greater in the dry season where more sources were found to be classified as very low risk of contamination. However, in all cases the level of contamination was more likely *to increase* following collection in water sources that were *initially free* from contamination. Results show that the degradation in water quality from the point of collection to the point of use was greater in the rainy season, which is more likely to be driven by the effect of seasonality on household environment. Filling the collection container at the point of collection and the use of a storage container at the point of consumption were found to be critical stages with respect to increasing contamination.

Conclusion: Understanding household behaviours in accessing and handling water during both rainy and dry season is necessary to target appropriate interventions to reduce contamination from the point of collection to the point of use.

Keywords:

Drinking water | Microbial water quality | Water collection | Contamination | Malawi

Introduction

The burden of fetching water remains widespread in settings where piped water on premises is not commonly available (Geere et al. 2010, Graham et al. 2016). Limited access to safe drinking water increases concerns related to water- and excreta-related (diarrheal) diseases (Mara and Feachem 1999). Whereas microbial safe water quality is paramount to break waterborne transmission routes, diarrheal diseases can also be transmitted by water-washed routes related to poor personal and domestic hygiene or food contamination (Mara and Feachem 1999). Interventions in water, sanitation and hygiene (WASH) are key to disrupt fecal-oral transmission routes and play a key role in preventing high rates of mortality and morbidity-related cases every year (Bartram and Cairncross 2010).

Lack of access to piped water on premises remains prevalent in Malawi (Cassivi et al. 2020b). In 2015, WHO and UNICEF estimated that 84% of the national population did not have access on premises and thus needed to fetch it. With the Millennium Development Goals (MDGs) period (2000-2015), efforts were put towards providing access to an improved water source in view of increasing coverage of access. Although improving water source technology (e.g., construction that is likely to protect the water from outside contamination) and providing good quality of water are generally recognized as ways to enhance a household's access, the benefits may be compromised by contamination that occurs during water collection including transportation and storage. Previous studies highlight an important challenge in maintaining water quality from improved water sources in households (Shaheed et al. 2014). This is further exacerbated as improved water sources aren't necessarily free from contamination to begin with (Bain et al. 2014a, Cronin et al. 2017, Shaheed et al. 2014). In order to address the fact that quality varied widely and was not synonymous with access or quantity, the inclusion of water quality indicators to monitor access to safely managed drinking water was put forward with the Sustainable Development Goals (SDGs).

Water contamination at the different stages of collection and use (i.e., at the source, during transportation, at the point of use, in household storage, in the drinking cup or glass) has been documented in previous studies (Churchill 1987, Harris et al. 2013, Rufener et al. 2010, Wright et al. 2004b). The risk associated with inadequate personal and domestic hygiene due to lack of access to water is especially critical in low socio-economic settings. Low income, rural living, and/or low education levels which are also recognized as important determinants of health (van Bodegom et al. 2009), were shown to be associated with a greater risk of *E. coli* contamination in water and faecal–oral disease transmission (Cronin et al. 2017, Elala et al. 2011, Trevett et al. 2005). It is however unclear what are the reported or observed critical points of contamination associated with the process and behaviours of an individual collecting water.

The aims of this study were two-fold. The first was to assess the impact of seasonality on water quality. The second was to understand households' behaviours in collecting water to further identify stages and critical points where post-collection contamination occurs. The appraisal of the reliability of self-reported measurements and sanitary surveys allowed us to identify critical points for post-collection water contamination.

Methods

Study Design

This cohort study was carried out in Malawi at the end of the rainy (March/April 2019) and dry (September 2019) seasons. A total of 375 households were randomly selected during the first season (5% margin of error, 95% confidence level) and a randomized subsample of 115 households were followed up during the second season (10% margin of error, 95% confidence level). Selected households had no access to water on their premises and were living in designated sites located in the Southern Region of Malawi. The three sites were selected through local partner guidance (i.e., Centre for Water, Sanitation, Health and Technology Development (WASHTED)) and local community and authority approval depending on water service levels and geographical components (i.e., population density and type of settlements). Two of the sites – Ndirande and Mbayani – were informal settlements located in Blantyre peri-urban areas mostly served by the Blantyre Water Board's public tap network. Blantyre is the financial and commercial centre of Malawi and the second-largest city. The third site – Chikwawa District - is a rural area lying around 60 km south of Blantyre. Four different villages from that district were included: Kadzumba, Frank, Bereu and Chambuluka.

Households were recruited through a voluntary participation process, and free and informed consent was obtained from all participant households. Local enumerators were hired and trained for data collection including field enumeration and water quality testing. This study obtained ethical approval from the National Committee on Research in the Social Sciences and Humanities (NCRSH) in Malawi (P.10/18/326) and the Human Research Ethics Board at the University of Victoria (18-1129).

Data Collection

A general module including a structured questionnaire, observations and water quality testing was conducted during the rainy season (Figure 4.1) (Annexe A). Households were visited once and administered a long questionnaire by the enumerators who were also required to record basic observations (e.g., coordinates, time). The questionnaire was based on and adapted from the UNICEF Multiple Indicator Cluster Surveys (MICS) with regard to SDG 6.1 and 6.2 monitoring questions and protocols (Khan et al. 2017), and included questions regarding general household information and WASH behaviours The questionnaire was double-translated for accuracy and administered in Chichewa which is the main local language. The adult household member most likely to be knowledgeable about the household's drinking water accessibility was selected to participate in the study. In addition to the questionnaire, the respondent was asked to provide a cup of water (that a household member would normally drink) and to show the source from where the water was collected for sample collection and subsequent water quality testing. Water sources that were not functional at the moment of the visit were revisited later in the day to be sampled by the enumerator.

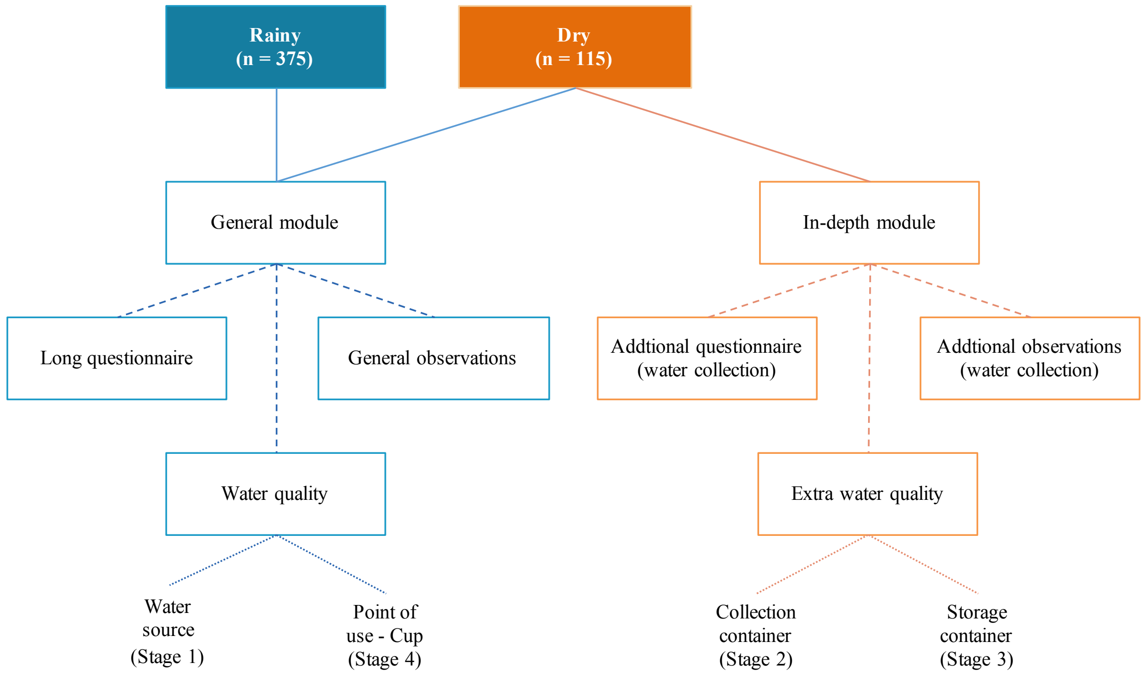

Figure 4.1. Graphical methodology of the study.

Results from the rainy season were used to improve methods and measures for the second visit. An additional in-depth water collection module was included to the general module and carried out on a two-day schedule during the dry season (Figure 4.1). The revised questionnaire was re-administered in selected households on the first day (Annexe B). Most questions were asked during both seasons (e.g., sources of drinking water, use of treatment) in order to be able to compare results and assess potential variations attributable to seasonality. Additional questions regarding the process of collecting water were included to identify critical points for post-collection water contamination. The additional questions related to water collection, though corresponding observations (only conducted during the dry season) were compared with self-reported measurements and sanitary surveys in order to identify critical points of post-collection water contamination.

During the dry season, at the end of the questionnaire, households were informed that the enumerator would come back during the following week to observe water collection and perform water quality testing at different stages of water collection. Household members were hence asked to walk again with the enumerator to the main drinking water source to fetch water. Participants were asked to proceed as they usually do while the enumerator passively observed while following (without asking questions or suggesting any behaviours). A sanitary survey based on observations was completed by the enumerators while walking to fetch water (Annexe C). Each observation recorded by the enumerators corresponded to a specific question asked to the respondent during the previous week. Samples of water were taken at four different stages of water collection: directly from the water source (i.e., point of collection) (S1); from the collection containers after being filled (S2); from the storage container (S3); and from a cup of drinking water (i.e., point of use) (S4) (Figure 4.2). If multiple containers were used to collect or store water, the sample was taken from the one with the highest volume. KoBo Toolbox (https://kobotoolbox.org) was used on Samsung Galaxy tablets for data collection, for administering the questionnaires, and for recording observations.

Figure 4.2. Stages of water collection sampled for water quality testing.

Water Quality Testing

The WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) methods and guidelines for direct testing of water in household surveys were applied to this study (UNICEF 2019a). Portable low-cost membrane filtration kits were used for testing microbial quality of the water samples. 100 ml water samples were tested using *Escherichia coli* (*E. coli*) as a proxy indicator for contamination exposure and water safety. Nasco Whirl-Pak™ Standard bags were used to sample water at the different stages of water collection and processed within 30 minutes. Hardy Diagnostics Compact

Dry™ EC plates were used for the enumeration of *E. coli*. Incubation belts (https://supply.unicef.org/s0000593.html) were worn during working hours and plates were later incubated in the laboratory at 37 °C for 18-24 hours. Colonies were counted the next day by an experienced laboratory technician and recorded in a database. *A priori* level of risk, as used by JMP, was used to classify results as follows: very low risk (< 1 cfu/100 ml); low risk (1-10 cfu/100 ml); moderate risk (11-100 cfu/100 ml) and high risk (>100 cfu/100 ml) (Lloyd et al. 1991). Absence (<1 cfu/100 ml) or presence (>1 cfu/100 ml) of *E. coli* was also used to further explore the critical points of contamination and risk factors.

Data Analysis

Data were compiled and analysed using StataSE14. Data available from both seasons, including the general questionnaire and observations along with water quality (i.e., water source, point of use), were first compared to study seasonal variations. The data from the in-depth water quality module collected during the dry season were further analysed to assess water quality at additional stages during water collection (i.e., collection and storage containers). Descriptive statistics including measures of frequency were used to analyse the distribution of the sample in terms of levels of risk and seasonal change. Critical points of contamination identified were described and interrater reliability between self-reported measurements and observations from the sanitary survey with regards to households' behaviours were assessed using the agreement and kappa coefficient. Kappa coefficients were assessed with the following ranges: ≤ 0 indicating no agreement and 1 indicating perfect agreement. Analytical statistics, i.e., Chi-square test of independence, Spearman's rank correlation, were used to assess the impact of different risk factors (e.g., type of container, cleaning practices) on post collection contamination and analyse the degree of association between water quality at different stages of water collection. Level of significance was reported when results fall within the 95% confidence level and when nonsignificant. Results were rounded off to the nearest unit after analysis to ease readability and interpretation, when necessary.

Results

Household Characteristics

The households included in the cohort were equally distributed geographically and were comprised of five people on average. The following statistics are presented by season (rainy, dry). Respondents were mainly women (89%; 86%) with primary education or higher (92%; 84%). The main types of water sources reported to be used by households were piped (30%; 34%), public tap/standpipe (30%; 35%) or tubewell/borehole (32%; 28%). All reported water sources are considered as improved by JMP (WHO/UNICEF 2018). Households generally reported using the same water sources during the rainy and dry seasons (94%; 97%). Of the households who do treat their water (18%, 36%), bleach or chlorine was used at the point of use (93%; 73%). Further, households mainly used a pit latrine for their toilet facility (94%) and a bucket or basin (98%) for handwashing. Key descriptive characteristics of households included in this study are presented in Figure 4.2.

Table 4.1. Descriptive characteristics of households included in the sample (rainy) and the subsample (dry).

Household characteristics	Rainy (n = 375)		Dry (n = 115)	
	%	n	%	n
Location				
Ndirande (peri-urban)	33%	125	33%	38
Mbayani (peri-urban)	34%	126	33%	38
Chikwawa (rural)	33%	124	34%	39
Household size (mean)		5		5
Respondent				
Sex				
Female	89%	333	86%	99
Education				
No education	8%	28	16%	18
Primary	51%	192	40%	47
Secondary or higher	41%	155	44%	50
Type of water source (main)				
- Piped (dwelling, yard, neighbour)	30%	111	34%	39
- Public tap/standpipe	30%	112	35%	40
- Tubewell/borehole	32%	121	28%	32
- Water kiosk	8%	30	4%	4
- Tanker truck	0.3%	1	0%	0
Water use				
Use same sources throughout the year	94%	351	97%	111
Use standing water	11%	40	10%	12
Use water treatment	18%	69	36%	41
- Add bleach/chlorine	93%	64	73%	30
Sanitation facility†				
- Flush (to pit latrine, to septic tanks)	1%	5		-
- Pit latrine w/ slab	33%%	25		-
- Pit latrine w/o slab	61%	225		-
- Ventilated improved pit	1%	3		-
- No facility	2%	7		-
- Other	2%	7		-
Handwashing facility†				
- Sink (in dwelling/yard)	2%	6		-
- Bucket/basin	98%	367		-
- No facility	1%	2		-
Shower location†				
- At home	83%	313		-
- Elsewhere	16%	60		-
- In the river	1%	2		-
† Information only collected in the general questionnaire at baseline (rainy)				

Seasonality – Change between rainy and dry seasons

Point of collection (S1)

Results from water quality testing at the point of collection (S1) show variations in the level of risk associated with a household's main drinking water sources. During the rainy season (n = 289), the number of *E. coli* colonies per 100 ml sample ranged from no colonies to too numerous to count (>200 cfu/100ml). No *E. coli* was detected in most water source samples indicating a low level of risk; three quarters of the water samples were collected in urban areas (Figure 4.3). Nearly 10% of the sources sampled during the rainy season were classified as high level of contamination, among most (88%) were located in rural areas, i.e., water quality at the water source was associated with the location of the households ($p < 0.001$). Samples collected in the dry season also show variations as *E. coli* counts ranged from 0 to 229 colonies per 100 ml (n = 107), but no plate was recorded as too numerous to count. No *E. coli* was detected in water sources falling below the third quartile of the sample. The proportion of the sources classified as very low risk was also skewed towards rural areas. The proportion of the water sources with higher risk levels was small although generally higher in the rural areas (Figure 4.3). Few of the water sources sampled during the dry season (3%), all located in the rural areas, were classified as high risk for water safety.

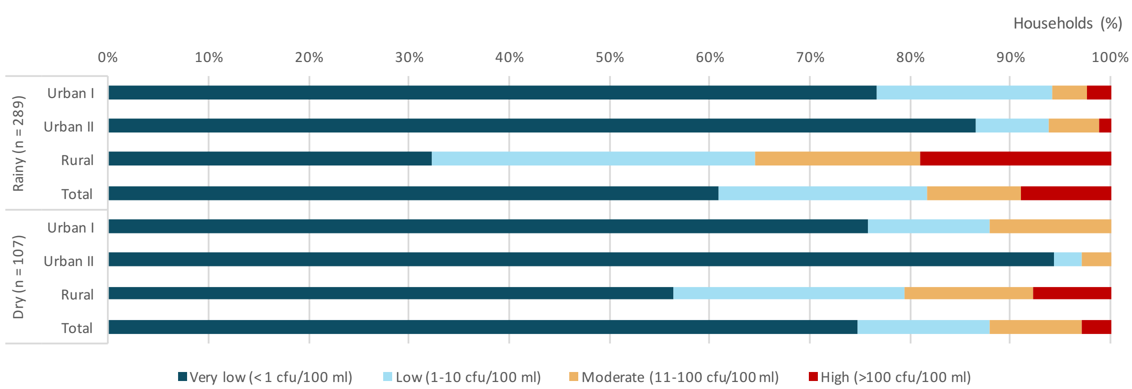

Figure 4.3. Proportion of the households relative to the level of risk of the water sources sampled (*E. coli*/ 100 ml).

The same type of water source (e.g., piped, public tap, borehole) was tested during both rainy and dry seasons in most households (58%) and the level of risk in the rainy season was found to be significantly associated to the level of risk in the dry season ($p < 0.001$). Results indicate that water quality of the sources remained the similar during both seasons for more than half of the households (57%) (Figure 4.2). The proportion of water sources with results indicating very low levels of contamination was greater in the dry season as oppose to the rainy season where more water sources were found to be classified as high risk. The level of risk was, however, observed to be higher in the rainy season (29%) compared to the dry season (13%). All sources that were found to be classified as high risk during the dry season were also classified as such in the rainy season. Overall, no *E. coli* was found during both seasons in half (50%) of the water sources and this was proportionally greater in the urban areas (75%) compared to the rural areas (20%).

Table 4.2. Change in the level of risk of water sources sampled during rainy and dry seasons.

		Dry season									
		Very low		**Low**		**Moderate**		**High**		**Total**	
		%	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**
Rainy season	**Very low**	50.0	41	12.2	10	1.2	1	0	0	63.4	52
	Low	14.6	12	2.4	2	0	0	0	0	17.1	14
	Moderate	6.1	5	1.2	1	1.2	1	0	0	8.5	7
	High	2.4	2	0	0	4.9	4	3.7	3	11.0	9
	Total	73.2	60	15.9	13	7.3	6	3.7	3	100	82

Point of consumption (S4)

The results show a greater difference in risk level at the point of consumption (S4) (Figure 4.4). In the rainy season, the proportion of samples classified in each risk level varied from 15% to 35%. More than half (60%) of the samples were classified as moderate or high risk, among which nearly half were taken from households located in rural areas. Water samples taken during the dry season at the point of consumption were mainly classified as very low or low risk (71%). Few samples were found to be classified as high risk for consumption (6%), and of those, most of the sample (40%) were taken in the household located in rural.

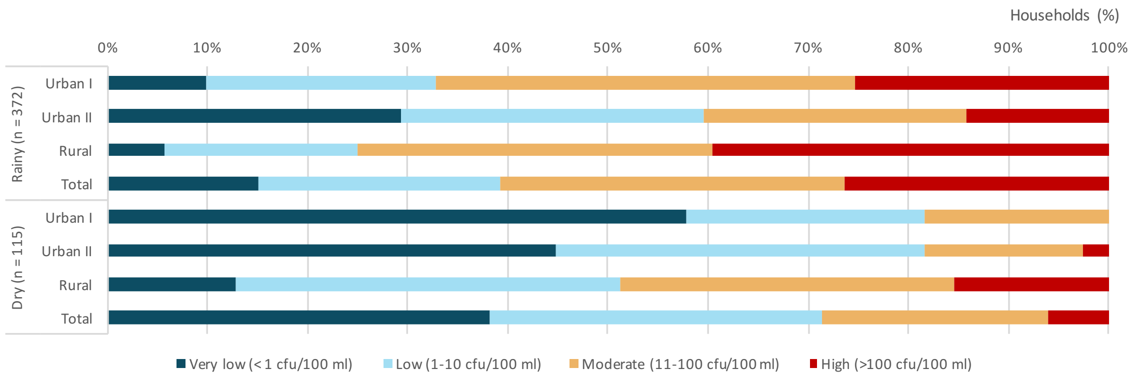

Figure 4.4. Proportion of the households relative to the level of risk of the water sampled at the point of consumption (cup) (*E. coli*/ 100 ml).

The change in water quality between rainy and dry seasons is less important at the point of consumption than the change observed at the point of collection where most sources were observed to be free from contamination during the rainy season. Level of risk at the point of consumption in the rainy season wasn't statistically associated to the level of risk in the dry season. The level of risk was higher during the rainy season in most households (58%) than in the dry season (15%). Risk levels were the same for both seasons in the remaining households (27%) (Table 4.3).

Table 4.3. Change in the level of risk of water sampled at the point of consumption (cup) during rainy and dry seasons.

		Dry season									
		Very low		**Low**		**Moderate**		**High**		**Total**	
		%	n	%	n	%	n	%	n	%	n
Rainy season	**Very low**	4.4	5	4.4	5	1.8	2	0.9	1	11.4	13
	Low	11.4	13	13.2	15	3.5	4	0.9	1	28.9	33
	Moderate	13.2	15	6.1	7	8.8	10	3.5	4	31.6	36
	High	8.8	10	9.6	11	8.8	10	0.9	1	28.1	32
	Total	37.7	43	33.3	38	22.8	26	6.1	3	100	114

Post-Collection Contamination

Two stages: Point of collection (S1) and point of consumption (S4)

Results show that the risk of contamination generally increased between the point of collection and the point of use. Water quality degraded from the point of collection, resulting in a degradation of water quality between the first and last stages of collection in rainy (67%) and dry (47%) seasons. As such, the proportion of the households where the level of risk remained the same (45%) or was even improved (8%) between the water sources and cup was greater in the dry season. A comparison of the change in the risk level between seasons shows that water quality remained the same during the dry season in many households although a degradation was measured during the rainy season (Figure 4.4). A degradation of the level of risk in the dry season mostly occurred - in three quarters of the cases - in households where a degradation between the point of collection and the point of consumption also occurred during the rainy season. Overall, a degradation of the quality during both rainy and dry seasons was observed in one third (33%) of the households while no improvement during both seasons was noted. Results from Spearman correlation analysis show significant correlation between the quality of water at the source and the point of consumption (r_s= 0.3241, $p < 0.001$) during the rainy season. The correlation between water quality from the point of collection and the point of consumption was lower during the dry season, but still significant at the 95% level of confidence (r_s= 0.2076, $p < 0.05$).

Table 4.4. Comparison of the change in the level of risk between the point of collection and the point of consumption between rainy and dry seasons.

		Dry season							
		Improvement		**Equivalent**		**Degradation**		**Total**	
		%	n	%	n	%	n	%	n
Rainy season	**Improvement**	0	0	1.2	1	2.5	2	3.7	3
	Equivalent	3.7	3	13.6	11	9.9	8	27.2	22
	Degradation	4.9	4	30.9	25	33.3	27	69.1	56
	Total	8.6	7	45.7	37	45.7	37	100	81

Four stages: Point of collection to point of consumption

Results highlight variations in the quality of water and level of risk at the four stages of water collection (i.e., point of collection, collection container, storage container, cup) during the dry season (Figure 4.5). The risk level remained the same across the different stages of water collection in one quarter (25%) of the households. Of those, most of the households (64%) were found to be using water classified as very low risk from the point of collection to the point of consumption, i.e., without being contamination at any stage.

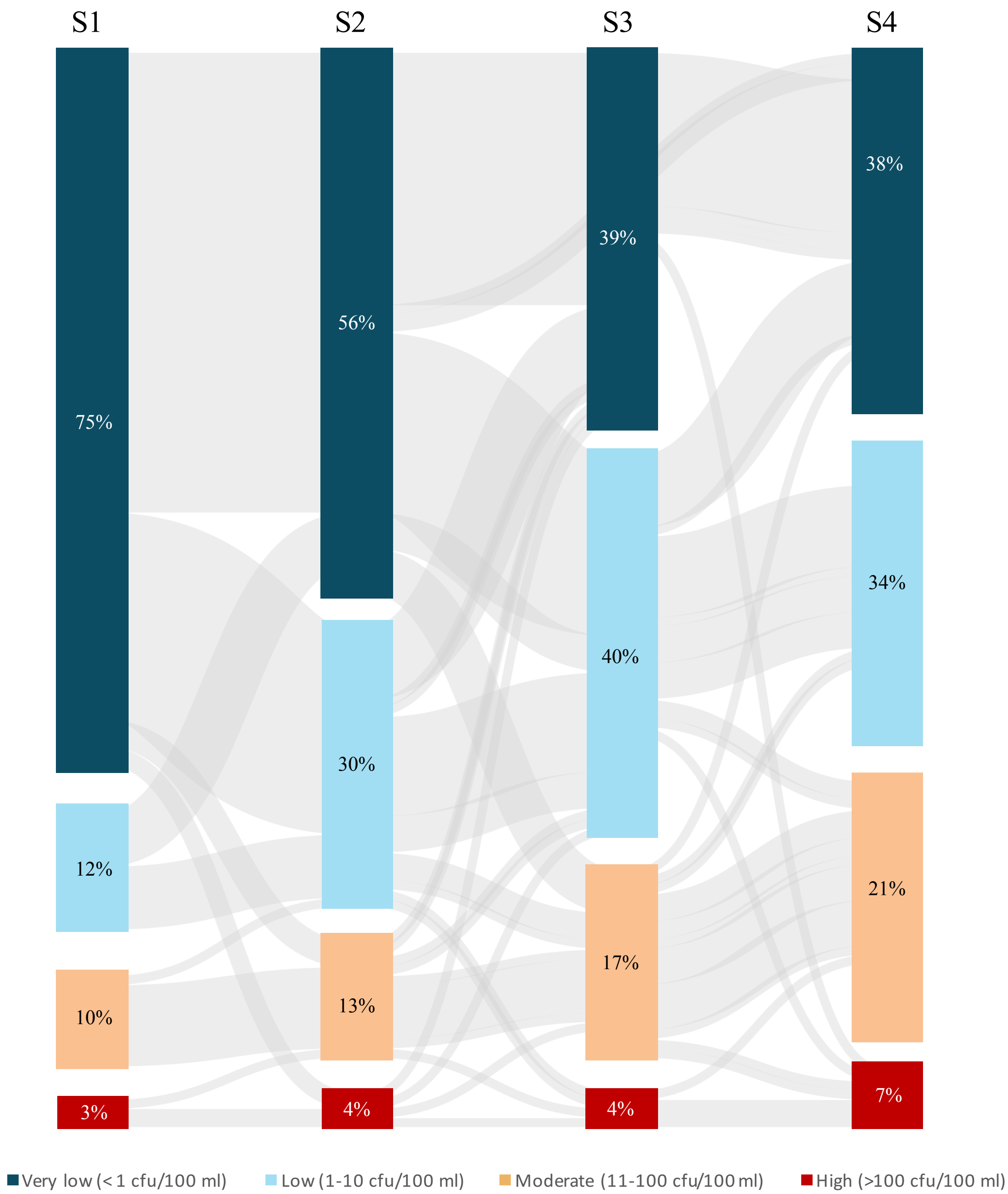

Figure 4.5. Change in the level of risk between each stage of water collection: water source (S1), collection container (S2), storage container (S3), drinking cup (S4). Shaded areas indicate overall changes between each stage of water collection.

Results from Spearman's rank correlation analysis shows significant correlations in the risk levels between all stages of collection (Figure 4.6). A strong correlation (r_s= 0.485, $p < 0.001$) between the quality of the water at the water source (S1) and the collection container (S2) which was sampled after being filled with water at the point of collection.

In two thirds of the cases the quality of the water remained constant. A change, i.e., either a degradation or an improvement, in the risk level between the first two stages was observed in one third of the households. A degradation in quality at the second stage was only observed in the households where water was classified as very low risk at the first stage (27%). An improvement in the risk level was observed in few (7%) of the households where a one-level change was made (i.e., low to very low; moderate to low; high to moderate).

Water quality remained the same from the collection container to the storage containers (S3) in half of the households. A degradation of the quality between the two stages was observed in one third (34%) of the households while an improvement was noted in the remaining households (66%). The correlation between the quality in the two containers was also significant ($r_s = 0.372$, $p < 0.001$).

A strong correlation ($r_s = 0.588$, $p < 0.001$) was determined between the quality of the water sampled in the storage container and in the cup used for consumption (S4). In addition to the quarter of household where water quality remained constant from the point of collection to the point of use (S4), the level of risk remained unchanged from the storage container to the cup in nearly half (40%) of households. A change in the risk level from storage to the cup was determined in the remaining households with a degradation (21%) or improvement (13%). Overall, a change in the risk level only at the household level (i.e., storage container or cup) was determined in 16% of households.

Although weak, a significant correlation between the quality of the water sampled from the point of collection and the point of use was identified ($r_s = 0.21$; $p < 0.05$). The strongest correlations were observed between the water quality sampled from the water source and that of the collection container ($r_s = 0.48$; $p < 0.001$) and from the storage container and cup ($r_s = 0.59$; $p < 0.001$). Further, water quality in the collection and storage containers were found to respectively relate to the previous (i.e., water source) and following steps (i.e., cup of water), but were not strongly associated within themselves ($r_s = 0.37$; $p < 0.001$).

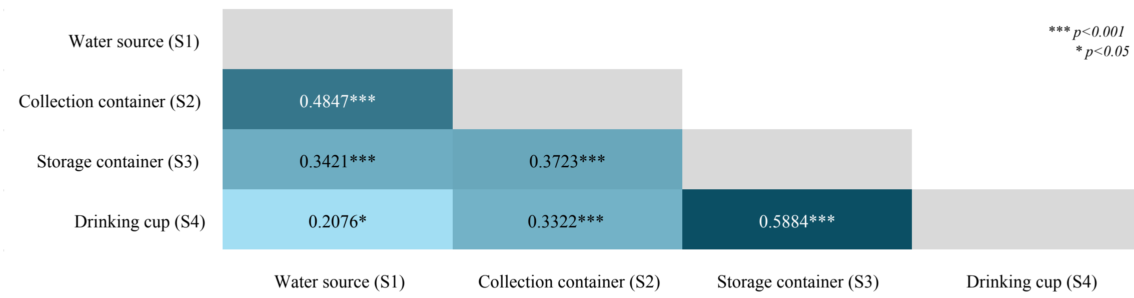

Figure 4.6. Correlation between water quality at the different stages of water collection (Spearman's correlation coefficient).

Household Practices and Critical Points of Contamination

Results of self-reported data and observations from the sanitary survey show variations in identifying water fetching practices and assessing critical points of contamination in water collection (Table 4.5). Percent agreement between self-reported and observed data varies from 39% to 100%. Overall, enumerators' observations were similar to what had previously been reported by the participants but Kappa coefficient generally shows low degree of agreement between self-reported and observed measures. Household members were, however, more likely to over-report good behaviours, as opposed to what was observed by the enumerators. The most critical differences between self-reported and observed measures were noted in the process of using containers for storage and/or cups for consumption. The comparison highlights the fact that the proportion of the households reporting rinsing or cleaning the different containers was greater than was observed. This might suggest that the households know what is "good practice", but do not consistently apply that in their daily routines. A relatively large difference was also observed between the proportion of households reporting (89%) and observed (54%) using a covered storage container. Very few households were observed treating water after filling the storage container (6%) although it was reported as being done in more than one third of the households (36%). In contrast, the proportion of households self-reporting using utensils or funnels instead of using a tap or pouring water–which would likely reduce cross-contamination at all stages of water collection (i.e., water sources, storage, cup)—was higher than what was observed by the enumerators during water collection. Although households mostly reported cleaning the utensil or the funnel they used to draw/collect water from the final storage container, enumerators recorded that many were inappropriately cleaned or unclean. Similarly, all households reported cleaning the drinking cup before filling it with water, but visible signs of contamination (e.g., animal waste, sediment accumulation) were observed by the enumerators in 20% of the households.

Table 4.5. Difference between self-reported measurements and observations from the sanitary survey with regards to households' behaviours.

	Self-reported		**Observed**		**Interrater agreement**	
	(n)	**(%)**	**(n)**	**(%)**	**Agreement**	**Kappa**
Water collection (n = 115)						
Container(s) is washed before collecting water	115	100%	76	66.1%	66.1%	0.0
Container(s) is rinsed before being filled	102	88.7%	73	63.5%	64.3%	0.10
Funnel, utensil or container is used to fill the container(s)	21	18.3%	3	2.6%	79.1%	-0.05
Storage (n = 115)						
Water is stored in a different storage container(s)	79	68.7%	69	60%	61.7%	0.17
Container(s) is stored inside	106	92.2%	89	77.4%	76.5%	-0.02
Storage container has a tap	5	4.3%	5	4.3%	100%	1
Use a distinct storage container (n = 52)						
Final storage container is cracked, leaking or unclean	4	7.7%	2	3.8%	88.5%	-0.05
Final storage container is covered	46	88.5%	28	53.8%	57.7%	
Storage container is refilled although not empty	17	32.7%	14	26.9%	51.9%	-0.14
A funnel, utensil or container is used to fill the storage container	10	19.2%	4	7.7%	76.9%	0.04
Consumption (n = 115)						
Anything is done to the water to make it safer to drink (i.e., water treatment)	41	35.7%	7	6.1%	65.2%	0.07
Cup is stored inside when not being used	115	100%	109	94.8%	94.8%	0
Cup is left in a place where it may become contaminated (e.g., on the ground)?	51	44.3%	49	42.6%	46.1%	-0.9
Method used to fill the cup:					39.1%	0.08
- Utensil used to fill the cup	56	48.7%	14	12.2%		
- Cup soaked inside the container	43	37.4%	78	67.8%		
- Water poured or tap used	16	13.9%	23	20%		
Utensils used to draw/collect water is cleaned/clean? (n = 50)	29	58%	14	28%	58%	0.22
Type of cup used for drinking water:					93%	-0.02
- Plastic cup	113	98.3%	109	94.8%		
- Metal or stainless cup	2	1.7%	5	4.3%		
- Glass	0	0%	1	0.9%		
Cup used for drinking water is cleaned/clean ?	115	100%	91	79.1%	79.1%	0

Risk Factors Assessment

The proportion of samples in which *E. coli* was present generally increases from the point of water collection, and multiple factors identified as critical points of contamination were found to have an impact on water quality at the different stages and between them. Results from a Chi-square test of independence shows that household location (i.e., urban or rural) was significantly associated with the presence of *E. coli* at all stages of water collection ($p < 0.01$). The levels of risk were higher in the rural areas during both study seasons and also degraded more significantly between the different stages except the change between the storage container and the cup.

Likewise, the type of water source as reported by participant households was significantly associated with the water quality at each stage of water collection in rainy and dry seasons ($p < 0.05$). The presence of *E. coli* was more likely to be observed in households using a public tap or borehole at all stages of water collection (Figure 4.7). A significant change in the level of risk was only observed between the first stages of collection (i.e., water source (S1) and collection container (S2)). Finally, most households reported rinsing the containers before filling and this was only associated with a change in the level of risk in water quality between the source and the collection container ($p < 0.05$).

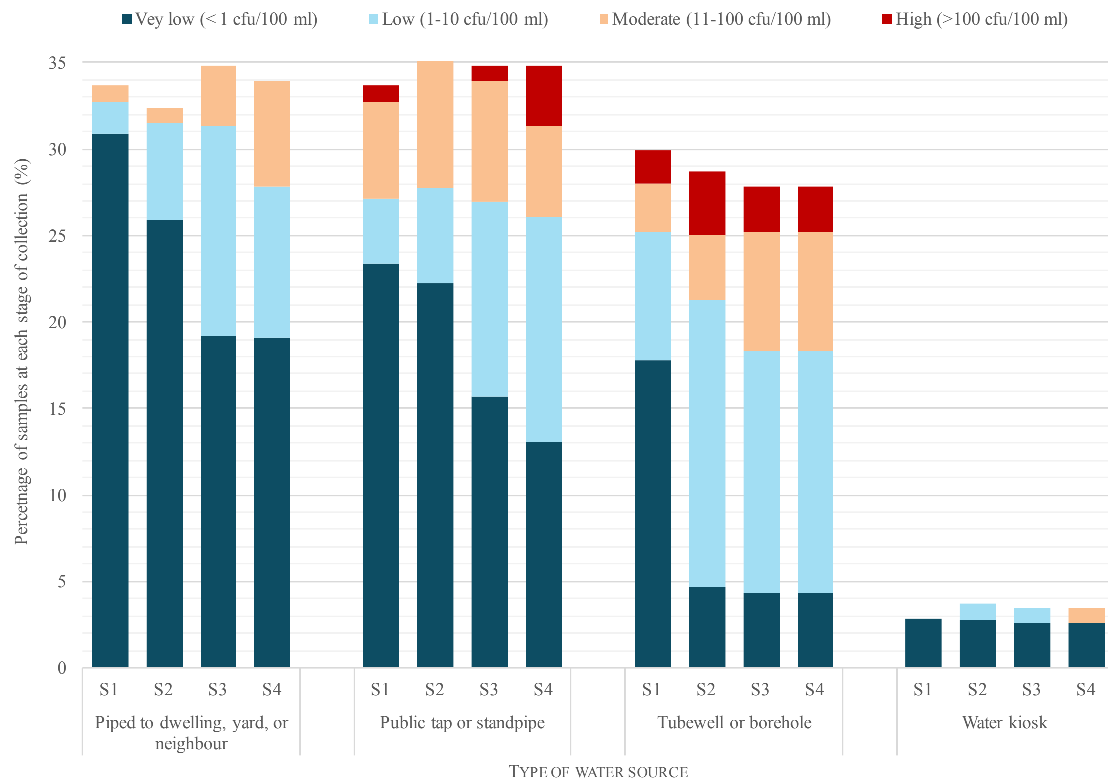

Figure 4.7. Water quality level of risk at each stage of water collection according to the type of source used by households.

The use of a storage container, as reported by participants, was found to be significantly associated with the presence of *E. coli* in the storage container ($p < 0.01$) and in the cup ($p < 0.05$). Results show that the water in households using the same container for water collection and water storage was 1.5 times and 1.4 times more at risk of being contaminated with *E. coli,* respectively in storage and cup, compared to households who use a different container for storage. Reported use of water treatment was found to be significantly associated with the presence of *E. coli* at the water source (p =0 .038) and cup ($p < 0.05$) only during the rainy season. Water quality in households that reported using water treatment had 1.4 times the risk of being contaminated with *E. coli* at the water source and 1.1 times the risk of being contaminated in the cup compared to households not using water treatment. No association was found between water quality and water treatment during the dry season. The self-reported storage of the drinking water cup (i.e., leaving cup on the ground) was found to be significantly associated with the quality of water in the cup ($p < 0.05$) but also in the storage container ($p < 0.05$). Households reporting leaving the cup on the ground were 1.4 times more likely to have contaminated water in their storage container and cup compared to households who don't leave cup on the ground. No association was, however, found in terms of the change between the storage container and the cup as levels of risk mostly remained the same.

Overall, the type of toilet facility (i.e., improved or unimproved), as reported by the respondents, was the only factor to be significantly associated with a change in water quality between the storage container and the cup. The level of risk in households using improved toilet facilities was 2.75 times as likely to increase between the last stages compared to households using unimproved toilet facilities. The risk level in the storage container was initially higher in households using unimproved facilities thus reducing the likelihood of an observed degradation at the last stages.

The use of covered containers for water collection and/or storage wasn't significantly associated with the presence of *E. coli* or to the risk level at the different stages of collection nor to a degradation in the level of risk between stages. Similarly, no association was found with regards to the use of a tool (e.g., funnel, utensil, other containers) both for filling the collection container at the water source and the cup at the point of use. Reported soap use for handwashing also was not associated with the risk level of the water samples. Finally, collecting rainwater or standing water around the dwelling wasn't associated with the level of risk at any stage or between them.

Discussion

This study highlights the variations in microbial water quality from the point of collection to the point of use and the level of risk associated with the different stages of water collection. This underscores the need to consider overall quality of water from the first stage to the last (Elala et al. 2011) and the different critical points of contamination.

Seasonality

Water quality remained constant from the point of collection to the point of use in most households but this was not associated with household location although greater degradation was observed in the rural areas. The effective use of chlorination in Blantyre Water Board's public tap network may explain the steadiness in water quality and the low rates of degradation between the different stages of collection in urban areas but this remains uncertain. This association should be explored further with a particular attention to the presence and/or absence of chlorine in water sources used by households.

Significant changes in water quality were measured between rainy and dry seasons. The quality of the water degraded from the point of collection to the point of use in most households especially in the rainy season where risk was higher, which is consistent with other studies (Kulinkina et al. 2016b, Kumpel et al. 2017, Mason 2015). Post-collection contamination in the dry season, which was proportionally lower than the rainy season, was observed in households where water quality degraded from the point of collection in the rainy season. Previous studies reported frequent water shortages during the dry season in Malawi (Adams and Smiley 2018), which compromise a water source's reliability and thus the quantity of water potentially collected. Limited access to water in the dry season could constrain households to more cautiously handle water in order to secure a sufficient quantity to meet their basic needs in water. Findings suggest that a household's behaviours may vary according to the sense of security in accessing water which may explain why water quality is more at risk when easily accessible (e.g., rainy season). There is a tendency to associate rainy seasons with water quality degradation due to source water degradation but results from this study suggests it is the household environment that is affected by seasonality.

Water Sources

Ensuring safe water quality at the point of collection is essential and remains a key intervention to improve households access to drinking water. (Bain et al. 2012a). A majority of water sources were initially classified as low risk for water quality during both seasons, but the proportion was greater during the dry season. Findings suggest that water quality at the point of collection is foremost a critical factor for deterioration of water quality the following stages of collection, especially in rural areas where more water sources were found to be classified as high risk. Particular attention should be paid in both urban and rural areas to the type of water source used by households as those different settings were found to be significantly associated with the presence of *E. coli* at the first stage of collection. Having access to a source providing water that is free from *E. coli* was significantly associated with an increased risk of contamination across stages of collection. These findings are consistent with other studies conducted in developing countries which demonstrated that contamination along with the collection chain was proportionally greater when water sources had low fecal contamination levels (Wright et al. 2004b).

The quality of the water at the water source was also strongly associated with the quality of water in the collection container, and a degradation between those two stages was only identified in cases where the water source was initially free from contamination. The stage of collecting water at the source should be considered as a critical point for contamination as water quality mostly remained constant in the following stages of collection. The use of a covered container and/or tools (e.g., funnel, spoon) to fill the container was, however, not associated with the contamination of the water in the collection container. Similar findings were found in Nepal where no significant change in water quality was associated with the type of containers and cleaning practices before water collection (Meierhofer et al. 2018). Such findings suggest that the collection containers are likely to represent the single most important point of contamination.

Households

Degradation of water quality after its collection may be further exacerbated by improper storage which may pose significant health risks (Trevett et al. 2005). A degradation in the quality between the collection container and the storage container was measured in a few households, but water quality mainly remained constant between the two containers. Similar results were found in Kenya where microbial water quality was significantly poorer in the storage containers than at the water source (Leiter et al. 2013). Additionally, the use of different containers reduced the risk of detecting *E. coli* in the storage compared to the use of a single container for both collection and storage. However, the type of storage container wasn't found to be associated with a change in water quality between the collection and the storage containers although the level of risk between the two containers was associated.

Whilst few households reported treating water, the use of water treatment was negatively associated with the quality of water (greater risk) exclusively during the rainy season. This may relate to the fact that households are treating water by concerns, but that that the treatment measures aren't sufficient. It is also possible that households using water treatment have a false sense of security, which may be exacerbated as a majority of households reported not treating water because they assume water is already safe at the point of collection (Cassivi et al. 2020c). Households who perceive that they are accessing clean water at the point of collection may be more likely to have a false sense of protection which may increase risk of recontamination following collection and this could be a risk factor for health (Banda et al. 2007, Francis et al. 2015, Leiter et al. 2013, Rufener et al. 2010). Other studies haven't found any significant association between treatment practices and the quality of water in the storage container (Leiter et al. 2013, Meierhofer et al. 2018). The use and handling of storage container(s) and water treatment(s) along with their associated beliefs should be further investigated to assess their effectiveness in settings without access to water on premises.

A deterioration can be expected when water is stored in the home (Elala et al. 2011), but findings indicate that quality would likely remain constant from the storage container (S3) to the cup of water (S4). The use of tools to fill the cup, instead of pouring water or using a tap, was not associated with a change in water quality at the point of consumption. This result is consistent with those from a study conducted in South Africa showing that a domestic water-handling hygiene education programme did not influence water contamination of the storage container in the household environment (Nala et al. 2003). No factor except the use of an improved toilet facility was found to be associated with a change in the level of risk between the storage container and the cup, indicating Findings from our study may suggest that a household's behaviours in handling water at the point of use were similar regardless of the different seasonal factors that were studied and this highlights the risk associated with household environmental factors of contamination. The effect of seasonality is more likely to impact drinking water than sanitation (Bartram et al. 2014), but the interactions and effect associated with a household's environment remains understudied.

Results from this study show the importance of carefully considering self-reported households' behaviours along with observational methods. Household members were more likely to over-report what could be considered as hygienic behaviours such as cleaning utensils and cups, using covered containers and/or using water treatment. However, respondents were also found to over-report the use of funnels or utensil to fill the container at the point of collection and the cup at the point of use, but this is not recommended. It is possible that respondents consider the use of a funnel or utensil as a good behaviour and which is why they over reported it. Such findings are consistent with previous studies that have highlighted a social desirability bias associated with households over-reporting favourable behaviour (Murphy et al. 2016, Null and Lantagne 2012, Park et al. 2016). The difference between self-reported and observational methods to identify risk factors and households' behaviours in accessing water and handling water should be explored further.

Overall, results from this study support the importance of holding a particular focus on interventions promoting safe water quality at the point of consumption (Clasen and Bastable 2003, Rufener et al. 2010, Trevett et al. 2005), but also highlight the need to focus on household behaviours in accessing water and managing the domestic environment during rainy and dry seasons. Considering the domestic environment with regards to seasonal change is important as water needs to be good at the point of consumption, which means going beyond having safe access at the point of collection.

Limitations

The presence of *E. coli* can be used as a general indicator of quality (i.e., most specific coliform indicator), but its application remains restrictive as it does not serve to identify exposure (e.g., source of contamination) and related outcomes (e.g., health). Additionally, *E. coli* as an indicator doesn't allow for the identification of other coliforms, pathogens (e.g., viruses, protozoa) or chemicals that are also recognized as potential threat for health (Mara and Feachem 1999, Fewtrell and Bartram 2001, Tallon et al. 2005). Despite its limitations for water quality assessment, *E. coli* remains, to date, the most reliable indicator of faecal contamination (Fewtrell and Bartram 2001, Tallon, Magajna et al. 2005, Standridge 2008, Levy, Nelson et al. 2012, Gruber et al. 2014).

Conclusions

Post-collection contamination is more likely to affect source water that is of a higher quality; stated differently, good quality water is easily contaminated while poor quality water generally stays poor without the use of water treatment. Safety is compromised at the first stage of water collection: filling the container is a critical point of water contamination. Ensuring safe drinking water at water sources should be done whilst keeping in mind that such improvement may influence a household's perception of risk and hygienic practices (i.e., handling water, use of water treatment) and lead to a false sense of water security. Further, particular attention should be paid towards the effect of seasonality on the household environment as water quality in the cup is strongly correlated to the quality in the storage container. Evidence from this study highlights the need for education and programming interventions to take water collection and handling at the point of use into account to ensure sustainable health outcomes.

Chapter 5

Manuscript Title:

Household preferences in accessing multiple drinking water sources

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AC lead conceptualization, design and implementation of the analysis with the supervision of CD, ET, and EOW. AC analyzed the results and wrote the manuscript. All authors commented and contributed to the final version of this manuscript.

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Abstract

Access to a sufficient quantity of safe drinking water is widely recognized as fundamental to ensure health and prevent water- and excreta-related diseases, reduce vulnerability to poverty and support development. Further evidence is needed to understand household perceptions and behaviours in choosing seasonal water sources for programmatic targeting towards the Sustainable Development Goal 6.1. The objective of this study is to describe the effects and variations associated to seasonal sources' reliability on households' behaviours in accessing water supply. Results from a seasonal cohort study conducted in Malawi, show that households were more likely to rely on multiple water sources during the rainy seasons, compared to the dry season where most households relied on a single water source. Source reliability (i.e., functionality and availability) and proximity to water sources (i.e., time to collect water, waiting time) were found to be important factors affecting household preferences towards multiple water sources. As a result, households were more likely to rely on alternative water sources, mostly unimproved, to secure sufficient quantities of water. The use of multiple water sources was, however, found to subsidize the benefit associated to having access to a single improved water source in terms of accessibility, quality, quantity. Ensuring reliable and continuous access to a single water source located at proximity to the household is a key intervention, which should not be held without consideration to households' behaviours in accessing water sources and seasonal variations. This is essential to improving global monitoring and designing appropriate interventions.

Keywords

Drinking water | Water supply | Multiple water sources | Seasonality | Malawi

Introduction

Monitoring access to drinking water is complex and global estimates generally rely on the main source of drinking water used by household members. In 2017, the WHO/UNICEF's Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) estimated that 71% of the world population had access to safely managed drinking water (i.e., drinking water from an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination). Although households that can afford to be provided with piped water supply mostly rely on a single source (e.g., intermittent piped water connection), households having limited access to water sources may need to rely on additional and alternative water sources as a coping strategy to meet their water needs (Adekalu et al. 2002, Madanat and Humplick 1993). In low- and middle-income countries where water sources are often located off-site, relying on multiple water sources is common and fundamental to secure households' consumptive (i.e., drinking and cooking) and non-consumptive uses (e.g., hygiene, cleaning, harvesting) (Elliott et al. 2017, Katsi et al. 2007). Considering the use of multiple water sources is essential to comprehend challenges in access to drinking water, propose appropriate solutions and effective global monitoring and implementation (Elliott et al. 2017, Vedachalam et al. 2017).

Households' preferences in accessing water sources are influenced by a number of factors including quality and distance. In terms of quality, household preferences aren't necessarily driven by the safest options in terms of microbial water quality (Kulinkina et al. 2016a) and perceptions mostly rely on aesthetic concerns (Foster and Willetts 2018, Tran et al. 2010). In some contexts, households would rather use nearby water sources of poorer microbial quality (e.g., rainwater, surface water) even though more distant sources providing higher quality water are available (Foster and Willetts 2018, Nyong and Kanaroglou 1999, Pearson et al. 2016, Tucker et al. 2014). Distance and collection time are key factors for access (Cassivi et al. 2018b, Devi and Bostoen 2009, Pickering and Davis 2012), and may impact the quantity of water collected by households (Cassivi et al. 2019). Households aren't, however, systematically collecting water from the nearest source (Pearson 2016) which suggest that priorities in accessing drinking water may vary. Other dimensions which relate to the source (e.g., accessibility, affordability, availability) and household needs (e.g., quantity, water use, storage) may influence households' decisions, but the influence of such factors remains understudied.

Seasonality will impact water fetching as it affects water quality and availability. The impacts of seasonality have been documented, demonstrating a deterioration of the quality in the rainy season, and a decrease in the quantity of water used by households during the drought periods (Mason 2015, Kulinkina, Mohan et al. 2016, Kumpel, Cock-Esteb et al. 2017), but the interaction between quantity and quality remain understudied. The collection of rainwater is a common alternative in settings without access to water on-site, allowing for greater quantities of water to be available for household use. The use of rainwater for drinking has, however, been demonstrated to be significantly associated with a high risk of microbial contamination (Foster and Willetts 2018, Helmreich and Horn 2009, Karim 2010, Meera and Ahammed 2006). Households may rely on rainwater as a main source of water during the rainy season, but insufficient storage capacity makes it difficult to sustain an adequate quantity throughout the year (de Lira Azevêdo et al. 2017, Elgert et al. 2016, Elliott et al. 2017, Tran et al. 2010). Furthermore, the use of alternative water sources during the dry season may be constrained by droughts or seasonal source availability (e.g., boreholes, wells, spring). A lack of access may lead to the supplementary use of unimproved water source or informally vended bottles and sachets of drinking water which may not meet quality standards (Elliott et al. 2017, Kumpel et al. 2017, Manjaya et al. 2019, Nyong and Kanaroglou 1999, Tran et al. 2010). Uncertainties in meeting daily water needs further compromise the quantity of water allocated to hygiene which may imply additional health risks (Tucker et al. 2014).

Very few studies have investigated the effect of using multiple sources on drinking water use at household levels and its integration to global monitoring highlighting considerable knowledge gaps in the literature (Elliott et al. 2019, Elliott et al. 2017, Foster and Willetts 2018). There is a need to further study the seasonal variations that may exist with regard to households' preferences and alternatives in accessing multiple water sources. Using seasonal data from urban and rural areas in Malawi, where a high percentage of water sources are located off-site (Cassivi et al. 2020b), this article seeks to assess the impact of water sources reliability on drinking water quality, quantity and accessibility (i.e., distance, time) in households fetching water. Understanding such interactions will help to determine where efforts should be made when working to design or evaluate interventions to improve access to water and how this could benefit to global monitoring.

The specific aims of this study were to: 1) describe the effects and variations associated with seasonal sources' reliability on households' behaviours in accessing water supply; and 2) to assess the relationships between multiple water source use and drinking water accessibility, quantity, and quality of water collected by households.

Methods

Study Area

The study was conducted in the Southern Region of Malawi in peri-urban and rural sites where households are generally relying on water sources that are located off-site. Sites were selected with regards to the household density and type of area. Two informal settlements (Ndirande and Mbayani) located in Blantyre area and four villages (Kadzumba, Frank, Bereu and Chambuluka) in Chikwawa district were selected upon local community approval.

Study Design

This study was conducted with a cohort study design. A total of 375 households were randomly selected for the first visit from which a subsample of 115 households was drawn for a second follow-up visit. Selected households were visited over a 6-month period interval to include the rainy (April 2019) and dry (September 2019) seasons.

Free and informed consent was granted from all households that were recruited under a voluntary participation process. This study was approved by the National Committee on Research in the Social Sciences and Humanities (NCRSH) in Malawi (P.10/18/326) and the Human Research Ethics Board at the University of Victoria (18-1129).

Data Sources

A structured questionnaire was used to survey the household (Annexe A; Annexe B). A general module which relates to the main water sources used by household members and water collection habits was common to both seasons. The same questions were asked twice to the participants (at the baseline and the follow-up), to allow for comparison between seasons. Information regarding the type of water source and use (i.e., reason why this source is being used over the others, use frequency), accessibility (i.e., location, collection time, waiting time), availability (i.e., quantity, seasonality), and affordability (i.e., fees), was collected for the primary, secondary, and tertiary water sources. Additional information with regards to household characteristics, water treatment, sanitation, and hygiene were also collected. The consenting adult who was more likely to be knowledgeable about drinking water collection was interviewed by the enumerators and was asked to physically show them the primary source of drinking water.

To measure water quality, the microbial water quality was measured using portable low-cost membrane filtration kits at the primary water source and in the household's cup of drinking water during both visits to allow for comparison. *Escherichia coli* (E. coli) was used as a proxy indicator for contamination exposure and water safety. For detailed information regarding water quality testing, see (Cassivi et al. 2020a). Level*s* of risk, as used by JMP, was used to classify results as follows: very low risk (< 1 cfu/100 ml); low risk (1-10 cfu/100 ml); moderate risk (11-100 cfu/100 ml) and high risk (>100 cfu/100 ml) (Lloyd et al. 1991).

Data Analysis

Data collected during both visits were compiled and analyzed using Stata SE14 statistical software package. At the household level, each water source that was identified by a respondent was ranked and characterized with regards to accessibility, availability, affordability, and quality. Results from households' assessment were further aggregated to identify general patterns in the different study areas. Chi-Square Test of Independence was used to determine whether there was an association between categorical variables (e.g., household location, type of water source) and the use of multiple water sources. Tests of normality were conducted on continuous variables including quantity and accessibility measurements, and the assumption of normality was rejected. Kruskal-Wallis H Test was used to determine if there was a significant difference in collection time and quantity of water collected in different groups. The degree of association between continuous variables (e.g., collection time, quantity of water) was assessed using Spearman's Rank Correlation. Data from the rainy and dry seasons were then compared using Wilcoxon Signed-Rank Test to identify seasonal variations in households' behaviours using multiple water sources.

A binary logistic regression was finally used to identify predictors of use (i.e., accessibility, quantity, quality) for multiple water sources. Levels of significance was reported when results fall within the 95% confidence level and when non significant.

Results

Water Sources

A significant difference in the use of multiple drinking water sources between rainy and dry season among visited households was found using Wilcoxon signed-rank test ($p < 0.01$) (Figure 5.1). Overall, 25% of the households reported using a single water source during both the rainy and the dry seasons. Fewer households reported using a single water source in the rainy season (32%), compared to dry season (51%). The proportion of the households using a single source was greater in rural areas than urban areas, during both seasons.

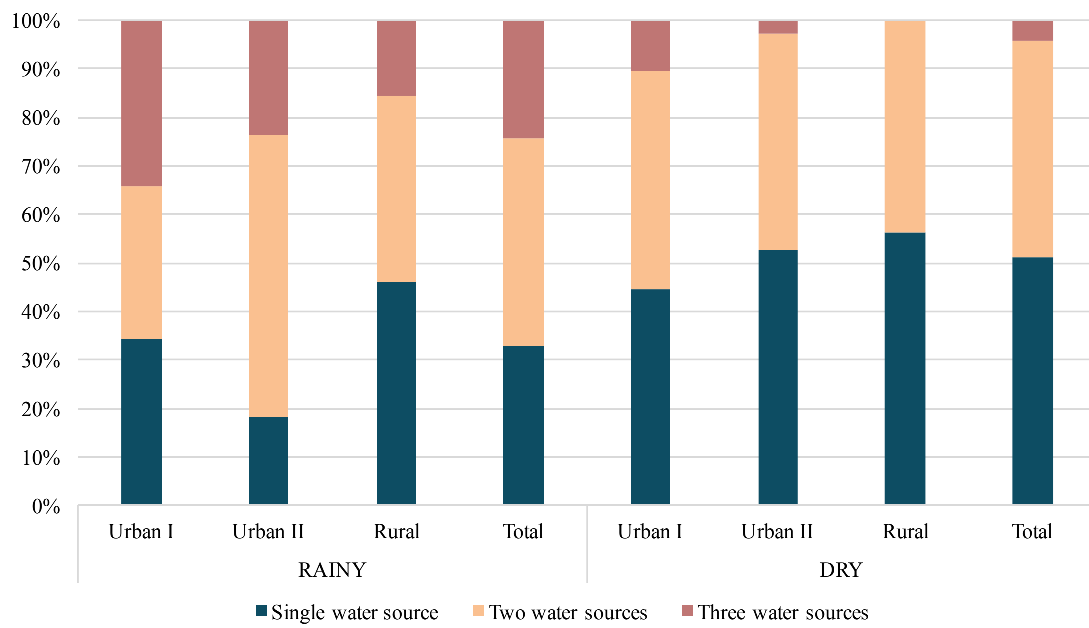

Figure 5.1. Proportion of the households using single or multiple water sources, by seasons (rainy or dry) and sites (urban or rural).

Single water source

The primary water sources reported by households were all classified as improved water sources (i.e., piped water, public tap or standpipe, borehole, water kiosk, or tanker-truck) (Figure 5.2). Public taps or standpipes were typically used in urban areas (43% in the rainy season; 33% in the dry season), as opposed to rural areas where boreholes were generally used (90% in the rainy season; 74% in the dry season). Overall, most (64%) households were using the same type of water sources during both the rainy and dry seasons, and this was equal in each urban and rural areas. However, using a significant difference in the type of sources reported being used by households was found between rainy and dry season ($p < 0.001$). The households that reporting paying for water at the primary water source (77% in the rainy season; 82% in the dry season) were more likely to use multiple water sources in the rainy season compared to the dry season (when they were more likely to use a single source). The association between the use of multiple sources and the need to pay for water at the primary water source was only significant in the rainy season ($p < 0.05$).

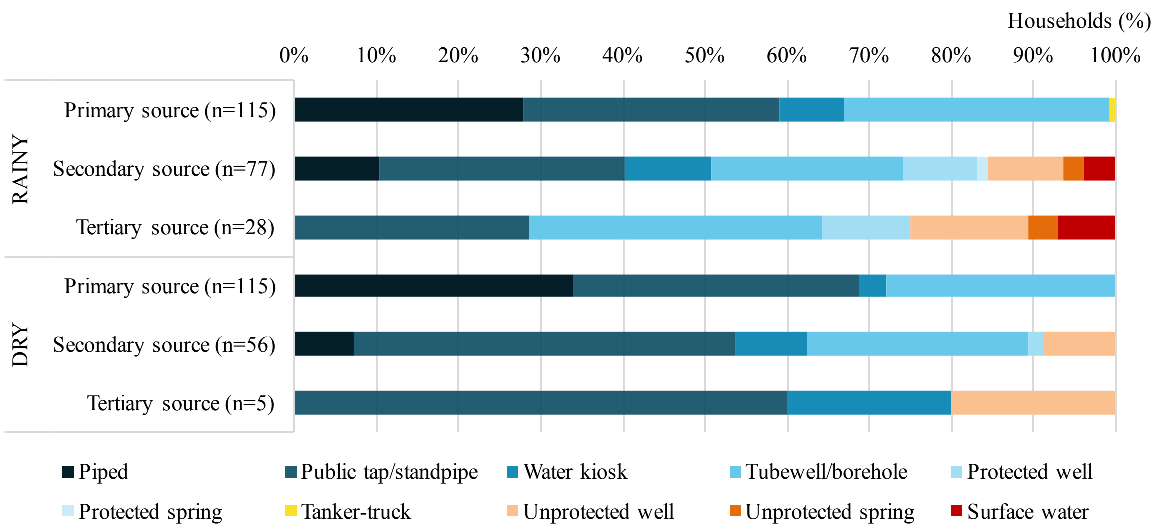

Figure 5.2. Type of water sources used by households (%), by season (rainy or dry) and sources (primary, secondary or tertiary).

Multiple water sources

The proportion of the households using multiple water sources was greater in the rainy season compared to the dry season. The use of multiple water source was significantly greater in urban areas ($p < 0.05$) than in rural ones. The use of a secondary water sources was generally greater in the urban areas in rainy (74%) and dry (51%) seasons. In rural areas, more than half (53%) of the households reported using a secondary source during the rainy season, while the proportion was lower (43%) in the dry season. In the rainy season, the proportion of the households using a third water source was greater in urban areas. In the dry season, a few households (4%), all located in urban area, reported using a third source. The type of sources used as secondary water sources were more diversified compared to the primary water sources. The use of alternative water sources such as protected or unprotected wells was reported in both seasons, in addition to springs and surface water (e.g., river, dam, lake, pond, stream, canal) which were also used in rainy season (Figure 5.2). Fewer households were relying on an unimproved water source as secondary alternative (16% in rainy season, 10% in dry season) as opposed to tertiary water sources (25% in rainy season, 20% in dry season)

Most households using secondary and tertiary water sources were relying on multiple water sources classified as improved (Figure 5.3). In the rainy season, most (84%) of the households using a secondary source were using an improved alternative as their secondary water source, among which several households (38%) also reported using a third source which was improved in most (75%) households. The proportion of households relying on a third water source was higher when the secondary water source was improved (compared to unimproved). In the dry season, almost all (91%) of the households that were using a secondary water source were relying on an improved water source. Households relying on an improved primary source and unimproved secondary source (9%) were not using the additional water source for drinking water. All households, however, reported collecting rainwater during the rainy season but this wasn’t reported as a source of drinking water. Finally, more than three quarters (78%) of the households reported not using standing water around their dwelling.

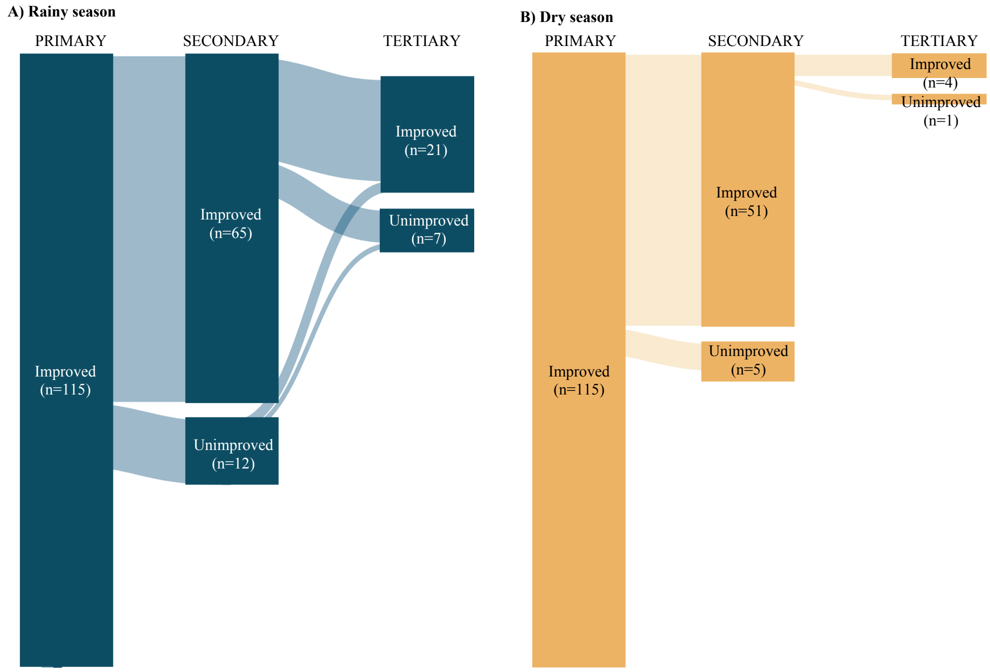

Figure 5.3. Type (improved/unimproved) of the primary, secondary and tertiary water source used by households, by season: A) Rainy; B) Dry.

Households Preferences

In the rainy season, households generally (82%) reported that their primary source of water was the one closest to their dwelling, and the proportion increased (90%) in the dry season. Source proximity was consistently given as the main factor for using the reported primary water source, followed by water availability (Table 5.1). Taste, perceived quality of water, and price were also reported as factors influencing a households' choice in accessing their primary water source. Households using a secondary and/or tertiary water source turned to the alternative mainly when the primary source was closed or not functional, and this was observed during both rainy and dry seasons. Many households also reported that their primary water source was sometimes broken and thus couldn't be used. Additional factors of preference that relate to water quality (i.e., don't need good water quality), quantity (i.e., need more water), and source accessibility (i.e., source is not accessible or too far, source is too crowded, water is too expensive) were also reported by households. Furthermore, households relied on secondary and tertiary water sources at similar frequencies, generally a few times per week (i.e., 1-2 days), and no significant difference in the frequencies of use reported was found between rainy and dry seasons.

Table 5.1. Factors influencing households' preference(s) in accessing water sources and frequency in using alternative options (%), by season (rainy or dry) and number of sources used (primary, secondary or tertiary).

		Rainy season			Dry season		
		1st	2nd	3rd	1st	2nd	3rd
Factor(s) use primary source*	Source is the closest	71%			83%		
	Water is always available	33%			35%		
	Water taste the best	12%			5%		
	Water is safe/clean	8%			4%		
	Waiting time is the shortest	4%			4%		
	Water is cheaper	4%			4%		
Factor(s) use alternative sources*	Source is closed/not functional		56%	64%		67%	80%
	Source is broken		32%	36%		12%	20%
	Source is too crowded		12%			5%	
	Don't need good water quality		10%	11%		1%	
	Source is not accessible/too far		8%	18%		3%	
	Need more water		3%	18%		5%	
	Water is too expensive		3%				
Frequency use (weekly)	Always (7 days)		8%	0%		10%	60%
	Mostly (5-6 days)		9%	7%		3%	40%
	Sometimes (3-4 days)		19%	4%		17%	
	A few times (1-2 days)		47%	43%		42%	
	Rarely		17%	46%		27%	
Multiple options possible							

Water Quality

Most households relied on a primary water source that was free from *E. coli* (very low risk), and the proportion was similar during the rainy (61%) and dry (75%) seasons. The proportion of the households using high-risk water sources was, however, greater in the rainy season (9%) compared to the dry season (3%). In the rainy season, more households using three sources were found to be using a primary water source classified as high risk (Figure 5.4), however, results from Chi-square test indicates that there is no statistically significant relationship between the number of sources used by households and the microbial water quality of the primary water source in the rainy ($p = 0.63$) or dry season ($p = 0.52$).

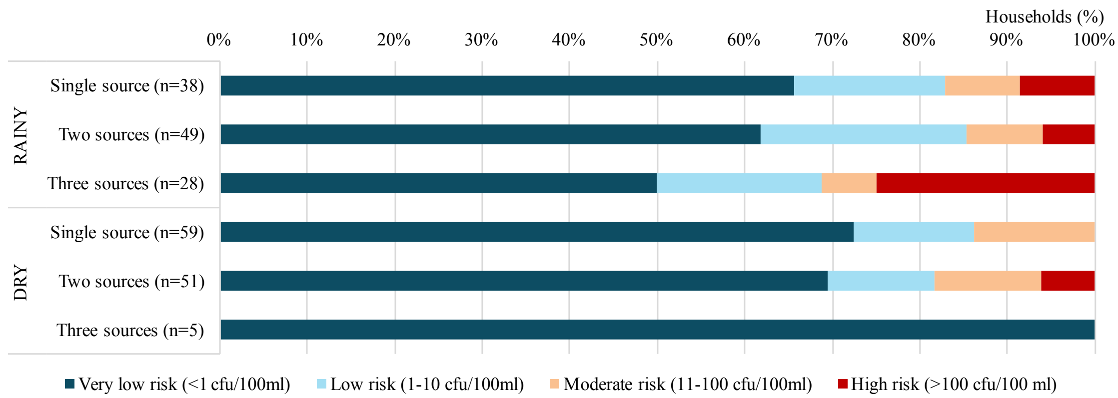

Figure 5.4. Microbial water quality (Level of risk) of the water sampled at the primary point of collection, by season (rainy or dry) and amount of water sources used (single, two, three).

The water quality degraded between the point of collection and the point of consumption. Supplementary results on post-collection contamination have been presented elsewhere (Cassivi et al. 2020a). Although water quality was generally better at the point of consumption in the dry season, no statistically significant difference was found between seasons in the quality of water at the point of consumption and the use of single or multiple water sources (Figure 5.5).

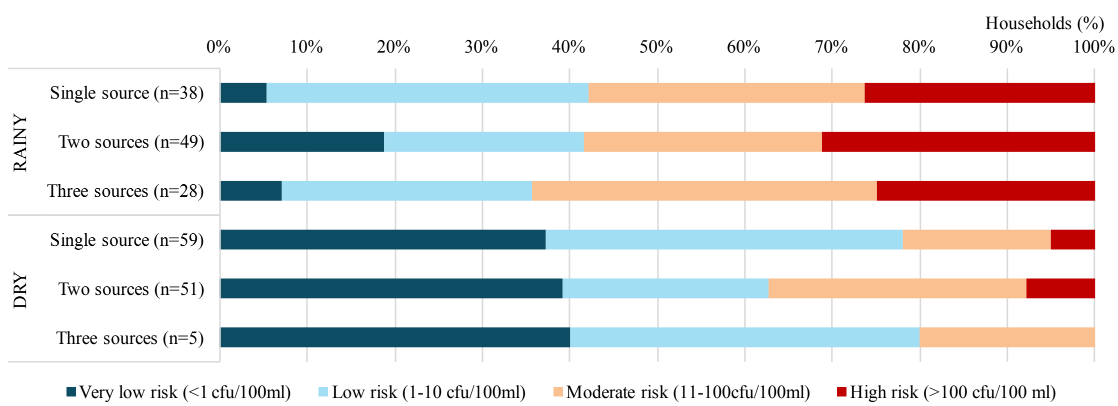

Figure 5.5. Microbial water quality (Level of risk) of the water sampled at the point of consumption (i.e., cup), by season (rainy or dry) and amount of water sources used (single, two, three).

Most households reported that they would be willing to walk further to collect a greater quality of water in rainy (80%) and dry (73%) seasons, but this wasn't significantly different between households using single or multiple water sources ($p = 0.33$; $p = 0.54$). A Kruskal-Wallis H test was conducted to determine if collection time was different in water quality levels of risk at the water source. A statistically significant difference between the levels of risk at the point of collection was found in the rainy season ($p < 0.05$), but no significant difference in collection time was found in the dry season ($p = 0.28$). Similarly, a significant difference in collection time was found between quality of water levels of risk at the point of consumption in the rainy season ($p < 0.05$), but this wasn't significant in the dry season ($p = 0.99$).

Accessibility

Results highlight variations in collection time associated with the use of multiple water sources. Round-trip collection times (i.e., get to the water source, collect water and come back) were generally lower for the primary water source during rainy (M = 18, *Mdn* = 10) and dry (M = 18, *Mdn* = 5) seasons (Figure 5.6). A Kruskal-Wallis H test was conducted to determine if collection time to reach the primary source was different in households using one or multiple water sources. Although reported round-trip collection time generally increased with the use of alternative water sources, no statistical difference in collection time was observed between the use of single and multiple water source in the rainy or dry season.

Finally, a Spearman's correlation was run to assess the relationship between collection time and trip frequency. A weak positive correlation was found between collection time and trip frequency, which was statistically significant in the rainy season ($r_s = 0.1927$; $p < 0.05$). No significant correlation was found in the dry season.

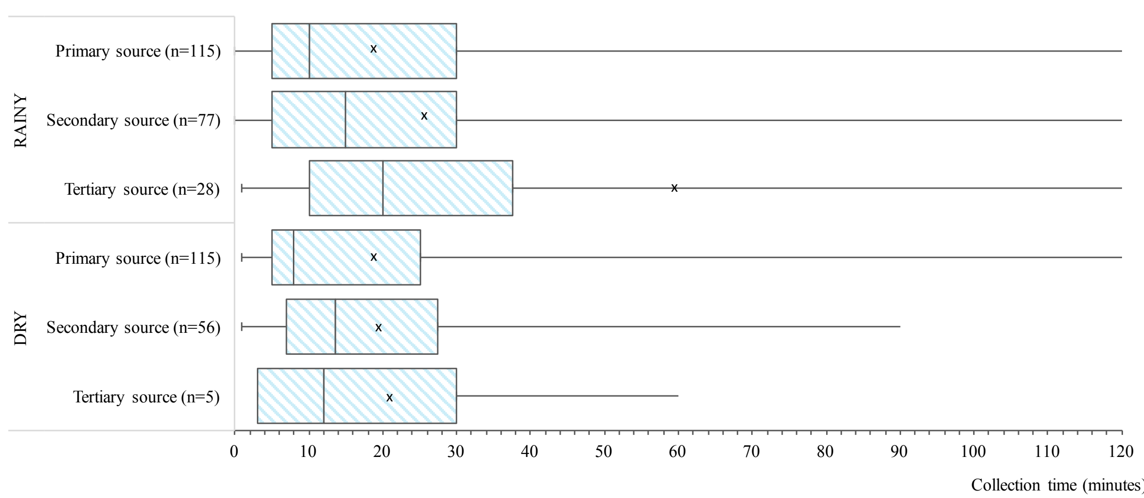

Figure 5.6. Round-trip collection time (minutes), by season (rainy or dry) and source (primary, secondary or tertiary) (bar: median; boxes 25th and 75th centiles; x: average).

Water Quantity

The average quantity of water collected each trip varying from 56 litres in the rainy season to 38 litres in the dry season. A Wilcoxon signed-rank test, however, revealed that the quantity of water collected each trip was significantly different between the rainy and dry seasons ($p < 0.001$). However, no statistically significant difference in the quantity of water collected each trip was found between households using single or multiple water sources. Most (70%) households reported they would collect more water if a new source was located closer to their dwelling and this percentage was significantly higher in households reporting using multiple water sources ($p < 0.05$). A Spearman's rank correlation was run to assess the relationship between round-trip collection time and the quantity of water collected each trip. No significant correlation was found in either the rainy or dry seasons. Although trip frequency wasn't significantly different in household using single or multiple water sources, the total quantity of water collected on a daily basis was, however, found to be positively correlated with the daily trip frequency in the rainy ($r_s = 0.40$; $p < 0.001$) and dry ($r_s = 0.53$; $p < 0.001$) seasons. Trip frequency varied from an average of 6 trips in the rainy season to 8 trips in the dry season but and no significant difference was found between rainy and dry seasons.

Overall, households generally (86%) reported receiving sufficient quantities of water to meet their households needs from their primary source of water. The total average quantity of water reported being collected wasn't significantly different between the rainy (M = 187 litres) and dry seasons (M = 189 litres). In the rainy season, of those that did not acquire enough quantities in the previous week, a majority (94%) of households reported relying on a second water source. Of those, several (31%) were also using a tertiary source. In the dry season, half (53%) of the households that reported inadequate quantities of water were relying on a second water source, and none were using a third water source. The daily quantity of water collected, as reported by households, was generally similar across households (Figure 5.7). A Kruskal-Wallis H test revealed a statistically significant difference in the total quantity of water collected daily between households using one, two and three water sources in the rainy season ($p < 0.05$). No significant difference between households using a single or multiple water source was, however, found for the quantity of water collected during the dry season.

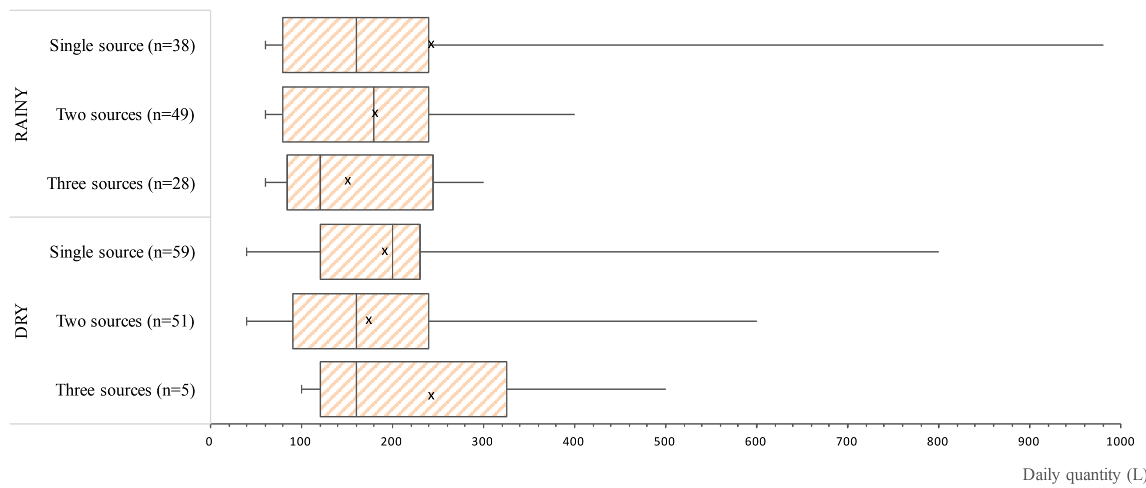

Figure 5.7. Total quantity of water collected daily (litres), by season (rainy or dry) and number of sources used (single, two, three) (bar: median; boxes 25th and 75th centiles; x: average).

Kruskal-Wallis H tests were conducted to determine if quantity of water collected was different for the different water quality levels of risk at the water source and household. In the rainy season, a statistically significant difference was found between the total quantity of water collected and the level of risk of the water at the point of consumption ($p < 0.01$), but this wasn't significant at the point of collection. Contrariwise, in the dry season, a statistically significant difference in quantity of water collection and water quality was observed at the point of collection ($p < 0.01$), and this wasn't significant at the point of consumption.

Predictors of Use

Table 5.2 shows the result of binary logistic regression models using either single (0) or multiple water source use (1) as the dependent variable. Multiple independent variables which relate to water quality (i.e., presence of *E. coli* at the point of collection and point of consumption), source accessibility (i.e., self-reported round-trip collection time main water source), and water quantity (i.e., daily quantity of water collected; insufficient quantity of water at least once in the last week) were controlled for.

Results from the rainy season show that households relying on primary water sources where *E. coli* contamination was found were more likely to use multiple water sources (OR = 7.24; $p < 0.01$), but the use of multiple water source wasn't associated with the water quality at the point of consumption. Households who did not use multiple sources reported less time fetching the water. No association was found between the use of multiple water sources and either daily trip frequency or water payment. Finally, households who reported having an insufficient quantity of water at least once in the last week were significantly more likely to use multiple water sources (OR = 3.61; $p < 0.05$) than other households. An extremely small difference was statistically found between the quantity of water fetched in households using multiple water sources (OR = 0.99; $p<0.05$). None of the predictors affecting the use of multiple water sources during the rainy season were found to be significant predictors for the dry season. Although the same variables were used during both seasons, the model was found to be statistically significant only for the rainy season ($R^2 = 0.2421$; $p < 0.001$).

Table 5.2. Logistic regression for the use of single or multiple water sources during rainy and dry seasons.

Variable	**Model I - Rainy**		**Model II - Dry**	
	OR [95% CI]	*p*-value	OR [95% CI]	*p*-value
Water quality				
Presence of *E. coli* (Primary source)	7.24 [1.88-27.22]	0.004	2.033 [0.73-5.63]-	0.173
Presence of *E. coli* (Drinking cup)	0.53 [0.06-4.46]	0.560	1.04 [0.44-2.348]	0.932
Accessibility				
Round trip collection time (Primary source)	0.96 [0.93-0.99]	0.009	0.99 [0.97-1.01]	0.206
Trip frequency (Daily)	1.06 [0.83-1.36]	0.625	0.97 [0.84-1.13]	0.708
Quantity				
Quantity of water collected (Daily)	0.99 [0.99-0.99]	0.022	1.00 [0.99-1.01]	0.338
Insufficient quantities of water (Previous week)	3.60 [1.06-12.26]	0.040	2.00 [0.76-5.24]	0.158
Constant	1.32 [1.34-13.09]	0.810	0.80 [0.18-3.31]	0.708
Observations (N)	83		102	
Pseudo R^2	0.2421	0.0003	0.0395	0.5900

Discussion

The use of multiple water sources is a function of seasonality and geography. Households are more likely to rely on multiple water sources in the rainy seasons than in the dry season, and this likely relates to water source availability and household factors of preference for use of alternative water sources which varies across seasons (Pearson et al. 2016). Significant variations in the use of multiple water sources were also observed between urban and rural areas. More households relied on multiple water sources in urban areas where water source density is generally greater, yet the availability is more limited compared to rural areas that mainly rely on boreholes (Adams and Smiley 2018).

Results highlight that the proportion of the households reporting that their primary source of water was closed or not functional was higher in the dry season than in the rainy season. Droughts generally increase failure of water sources in Malawi (Calow et al. 2010), and although the link remains unclear, this finding may represent a factor that constraint possibility for using multiple water sources. Multiple factors that relate to accessibility, quantity, and quality are shown to drive households' preferences and behaviours in accessing drinking water (Kulinkina et al. 2016a), but these factors were only found to be significantly correlated to single versus multiple sources in the rainy season.

In the rainy season, the need to pay for water at the primary water sources was identified as a factor that influenced households to use a secondary or tertiary water source. Households also reported collecting rainwater but none of the respondents referred to it as a main, second or third source of water. The use of rainwater as an informal alternative may be used to supplement the quantity of water available but remains informal conservation practice in Malawi (Mulwafu et al. 2003), contrary to other countries such as Vanuatu or Vietnam where households have a preference for rainwater (Foster and Willetts 2018, Tran et al. 2010). The potential of harnessing rainwater harvesting to increase quantity of water should be explored further.

Distance was found to be the most important predictor for selecting a primary water source among households without access to water on site. Households using a single improved water source were more likely to walk less and to collect more water on a daily basis. Collection time wasn't associated with microbial water quality of the water source and this finding is consistent with a study conducted in Ethiopia which found that households preferred to use closer source without regards to water quality, rather than more distant but higher quality sources (Tucker et al. 2014). Aesthetic factors and taste were found to be households preferred characteristics when drinking water, and this was previously demonstrated to be associated to water quality of the water (Furlong 2010).

Although all households relied on an improved drinking water source for their main supply, a larger range of source types were reported being used as secondary or third options. The last alternative water source used was more likely to be unimproved than improved. Surprisingly, households using unimproved water sources were less likely to use additional water sources suggesting they are relying on the last option available. Households using water where at the point of consumption it has a microbial quality in the high risk category were more likely to rely on multiple water sources. Importantly, this wasn't associated with water quality at the point of collection. This finding may suggest that households are mixing water from improved and unimproved water sources in their storage container, which likely contributes to post-collection contamination. A degradation of the quality between the point of collection and the point of consumption was mostly observed in the rainy season (Kumpel et al. 2017, Pearson et al. 2016), and this may also relate to water handling and the household environment (Cassivi et al. 2020a). Such results emphasize that water quality of alternative sources should be monitored across seasons (Kumpel et al. 2017).

Results show that the quantity of water collected was similar to, though slightly greater among households using a single source compared to households using multiple water sources, which suggest that households found sufficient quantities of water to meet their needs from their primary water source. Households who use alternative water sources did not receive a sufficient quantity from the main water source. This finding is consistent with those from a study conducted in Zimbabwe which found that households were commonly using alternative water sources that were often unimproved to secure adequate quantities of water (Katsi et al. 2007). The link between the use of multiple water sources for different purposes should be explored further. A household's decision to access drinking water may be influenced by quantity and quality of water required for different uses (Madanat and Humplick 1993).

The quantity of water collected each trip wasn't associated to the collection time, and the overall quantity of water wasn't related to water quality at the point of collection. Trip frequency was, however, found to be associated with the total quantity of water collected on a daily basis, although not directly influenced by the collection time required to fetch water. Such findings suggest that trip frequency is an important factor to consider when monitoring access to drinking water which may be used as a proxy indicator for water quantity.

Recommendations

Ensuring reliable access to a single water source is important and beneficial, but should be put forward cautiously as its effects can be subsidized by the use of alternative water sources, which may vary from rainy to dry season. Ensuring that sources are functional is key to secure access to water especially during droughts. Results from this study highlight the need to control for seasonality and consider the potential use of multiple water sources. Households will rely on multiple water sources that are more likely to be unimproved to secure quantities of water if they cannot rely on the primary water source, and this should be a matter of concern for monitoring access to water. Along with improving the design and effectiveness of global monitoring, incorporating seasonality and multiple water source use is necessary to improve data interpretation and policy advice (Elliott et al. 2019, Elliott et al. 2017, Vedachalam et al. 2017).

Discussion

This dissertation gathers evidence, from a systematic review as well as retrospective and prospective observational data, directed towards improving assessment and monitoring of access to drinking water in low-and middle-income countries.

Access to Drinking Water: Theoretical Framework

Access to water has always been indispensable for human life, but has only relatively recently been recognized as such through the human right to water and sanitation (UN Committee on Economic Social and Cultural Rights 2010). The importance of improving access to water and sanitation gained notoriety globally, in 2000, with the advent of the Millennium Development Goals (Bartram et al. 2014). At the time very few studies, including White et al. (1972)) and Cairncross and Feachem (1993)), considered as precursory to further research, had investigated water access in low-and middle-income countries, and no theoretical framework existed. Studies assessing the impact of water accessibility, mostly from a health perspective, were later conducted (Chapter 1).

Following efforts to meet the MDG water-related target, established as having the proportion of the population without sustainable access to safe drinking water, by 2015, many people gained access to water thought different water supply programmes and interventions aiming to provide access. This same pattern was observed in Malawi (Chapter 2). As a result, the proportion of the population with access to water sources considered to be “improved” (i.e., one that by design type can be considered to adequately protect the source from outside contamination, particularly faecal matter) increased from 72% in 1990 (the baseline year) to 91% in 2015 (UNICEF/WHO 2015). The apparent progress in terms of access, has, however, masked the importance of going beyond the typology of the source, and this has been highlighted in this study conducted in Malawi and other studies conducted towards the end of the SDGs (Adams and Smiley 2018, Bain et al. 2012b, Cassivi et al. 2018b, Dar and Khan 2011, Devi and Bostoen 2009, Godfrey et al. 2011).

Transitioning from the MDG to the SDG, the indicator used by JMP to monitor access to drinking water built on the previous “access to an improved water source” but also incorporated aspects of accessibility (i.e., located on premises), quantity (i.e., available when needed) and quality (i.e., free from contamination) from which the baseline was set as 71% of the population in 2015 (WHO/UNICEF 2017a). The extent of change related to the switch to safely managed is unknown in Malawi, but a MICS survey along with a water quality module is currently underway, which will offer interesting analysis to identify new trends in access (Chapter 2) and further understand issues that relate to water quality (Chapter 4). With a growing interest from researchers, the MDGs/SDGs' era prompt a reduction in the gap in knowledge surrounding access to drinking water. Several studies were conducted using national household surveys and census, to improve estimates' accuracy and revisiting statistical approaches to monitor progress (Ezbakhe and Pérez-Foguet 2019, Fuller et al. 2016). Other studies were also conducted using different methods and metrics to measure access to water, yet no consensus on standardized methods has yet been put forward. Results from Malawi suggest promising alternatives to self-reported measures (Chapter 3).

Although the body of literature is larger, published studies yield few insights for better understanding the impact of the location of primary and secondary/alternative water sources on the quantity and quality of water accessible for households fetching water while controlling for seasonality, and this has been an important focus in this study. Results from the systematic study (Chapter 1) highlight that most studies available were conducted under a cross-sectional study design which prevents the assessment of causation and temporality. Multiple factors and methods were explored, as part of this seasonal cohort study conducted in Malawi, to improve understanding of issues surrounding access to water and monitoring progress in settings where fetching water is necessary.

Household Practices and Preferences

Households without improved water sources on their premises face different challenges related to water source reliability and seasonality, which were found to be leading factors that impact' preferences and behaviours in accessing in Malawi, as addressed in Chapter 5. Households were found to rely on multiple water sources to meet their needs in water and this is consistent with findings conducted in Zimbabwe and Ghana (Alhassan and Kwakwa 2014, Katsi et al. 2007). Primary water sources reliability, which is mostly compromised by functionality, water shortage and queue time, grounds the use of multiple water sources. Results (Chapter 5) highlight the need to revisit the idea of relying on information collected on the use of a single water sources and consider the extent of alternatives available to households without access to water on their premises.

Important variations in the use of water sources were found between rainy and dry seasons (Chapter 5). More households were reporting using a single water source during the rainy season, as opposed to the dry season were a majority of households were relying on alternatives water sources, and this is consistent with other studies (Pearson et al. 2016, Tucker et al. 2014). Multiple factors that relate to water accessibility, quantity and quality were found to influence the household needs to rely on alternatives water sources in the rainy season, but no factors explained variations observed in the dry season. Such findings suggest that water sources may be more accessible in the rainy season, encouraging households to select the most reliable water source which will ensure sufficient quantity of water. Households may be collecting greater quantities of water during the rainy season but results show that water is also more likely to be contaminated at the point of consumption. Lack of direction in households' preferences during the dry season highlight the challenge faced to access drinking water when fewer options are available, moving towards a more intuitive behaviour to secure access. Further research is necessary to understand the impact of seasonality on household behaviours in accessing drinking water as this remains understudied.

The quantity of water collected by households was associated to round-trip collection time in the rainy season and households using a single water source were found to collect more water, but this wasn't significant in the dry season. Current knowledge was based on the largely used but understudied "water plateau" graph qualitatively depicting the relationship between distance and collected water which, however, relates to findings from anthropological studies conducted in the 1970s (White et al. 1972). The relationship between round trip collection time and the quantity of water collected was, however, found to be linear, with a general increase in the quantity as time decreased, and this is consistent with the other studies that were assessed in the systematic review (Chapter 1). Water quantity was significantly associated with trip frequency, which wasn't *de facto* associated to collection time, and this is consistent with findings from a study conducted with other informal settlements in Malawi (Adams 2018). Findings suggest that improving source proximity may provide the opportunity to augment the frequency of trips which will be directly beneficial in securing the greatest quantity of water. Thus, the evidence gathered in this study challenges the hypothesised “water plateau” qualitatively depicting a steep decline in water consumption from 0 minutes (i.e., on premises) to about three minutes, after which the amount used would plateau until 30 minutes where a further decline would be observed (Cairncross and Feachem 1993).

Water and Hygiene: Implications for Health

Interventions in water, sanitation and hygiene are key to improving health and prevent water- and excreta-related diseases (Bartram and Cairncross 2010). Overall, the benefits of improving access to drinking water are maximized and fulfilled by the use of improved sanitation facilities and good hygiene practices. The quantities of water collected on a daily basis will influence the allocation of water for different uses and hygiene practices in households, and this is expected to vary across seasons. The quantity of water collected as reported by households in Malawi was higher in the rainy season compared to the dry season (Chapter 5), which is similar to what has been found in other countries (Arouna and Dabbert 2010, Hadjer et al. 2005). Insufficient quantities of water curtail availability for hygiene, as expected in the dry season (Tucker et al. 2014), and increases prevalence of water-washed diseases (Cairncross 1999, Howard and Bartram 2003, Stelmach and Clasen 2015). The variations that are found between rainy and dry season in terms of water availability prevent consistent practices which increase health-related concerns such as water- and excreta- related diseases (Mara and Feachem 1999).

In Malawi, the rainy season was associated to an increase in water quantity along with a degradation of water quality from the point of collection to the point of use (Chapter 4), which is consistent with previous studies conducted in Nigeria and Philippines (Kumpel et al. 2017, Mason 2015). A statistically significant association was also found between the total quantity of water collected and the level of risk of the water at the point of consumption in the rainy season (Chapter 4), which suggest that variations are most likely driven by the effect of seasonality on the household environment. The quantity of water allocated for personal (e.g., hand hygiene) and domestic hygiene (e.g., clean containers and storage) plays a critical role in mitigating the effect of post-collection contamination which can significantly compromise quality of water, especially in context where the main drinking water source is free from contamination (Elala et al. 2011, Wright et al. 2004b). In addition to water-washed routes of transmission, limited water availability enhances risk of waterborne diseases through the ingestion and the exposition to contaminated water (e.g., consumption, food contamination) (Mara and Feachem 1999). There is a need to focus on the variations between rainy and dry seasons in terms of personal and domestic hygiene to assess implications for health, and this goes through better understanding household behaviours in accessing and handling water from the point of collection to the point of use.

Universal Access: Methodological Framework

There are important gaps between having access to water on premises and accessing water off premises. Although ensuring universal and equitable access to water on premises by 2030 represents an aspirational goal, it appears nearly unrealistic as more than 2.1 billion people did not benefit from safely managed drinking water on their premises in 2017 (WHO/UNICEF 2017b). In 2018, the UN reported that the world was not on track to meet the SDG water and sanitation goals and called for an increased attention on efforts to monitor and reduce inequalities in access to drinking water (United Nations 2018). Important inequalities between urban and rural areas as well as population growth and urbanization exacerbate apprehension with regard to lack of access to water, sanitation and hygiene in low-and middle-income countries (Adams and Smiley 2018, Bain et al. 2014b, Pullan et al. 2014, Yang et al. 2013). Further, 30% of the urban population were living in informal settlements in 2014 (World Bank 2018), which increases concerns regarding lack of access to basic services in urban areas. Efforts should target the most vulnerable populations to reduce the gap in access and ensure safe and sufficient quantities of water from at least one reliable primary source located at proximity across seasons. It should be considered that people may rely on more than one source and strive to ensure that their "ensemble" of sources are aligned and compatible with safely managed drinking water sources.

Findings from Malawi highlight the necessity to move towards the paradigm of ensuring safe water at the point of collection and further acknowledge the importance of securing water safety at the point of use in settings without access to water on premises, which has been discussed in previous studies (Clasen and Bastable 2003, Rufener et al. 2010, Trevett et al. 2005). Programming should target providing safe drinking water along with appropriate sanitation and hygiene interventions at the point of use to ensure sustainable health outcomes and reduce the burden of water- and excreta-related diseases (Bartram and Cairncross 2010). This will not be achieved without bringing forth educational programmes to promote safe household and environmental hygiene. Household preferences and needs must be considered to identify and implement appropriate interventions to improve access to drinking water with respect to general definition of access. Water source proximity and reliability is also important and this includes accounting for the use of multiple water sources in view of ensuring sufficient quantities of water. Additionally, seasonality and associated impacts on water accessibility, quantity and quality should be integrated as a key component in the design and implementation of interventions aiming to improve access to water, and this should also be considered for monitoring access.

A definition and indicators of access along with methods and metrics should be developed and implemented as complementary components in a comprehensive framework of access which reflect the reality. Generating evidence to better understand households' behaviours in accessing water, which represent the overall objective of this study, is a fundamental foundation to better define what should be considered when monitoring access to water. Multiple components of access have been explored in this study among which post collection contamination, seasonality and water source reliability were proved to be important factors influencing provision of safe and sufficient quantities of water in households without access on their premises (Chapter 3-4-5), and should be considered in monitoring efforts.

Monitoring global access to drinking water is complex as it is largely reliant on data available. Improving methods and metrics used to generate estimates is necessary to increase data availability and improve accuracy of indicators used to monitor progress (Adams and Smiley 2018). Results from this study (Chapter 3) highlight the potential of including easily replicable alternatives to self-reported metrics such as observations and GPS-based measurements (Ho et al. 2014, Jagals 2006, Pearson 2016). Methods such as observations and GPS-based measurements that are easy to implement in household surveys, should further be integrated to household surveys in addition to self-reported methods. This is necessary to readily monitor a wide range of components and increase confidence in global estimates. Comprehensive indicators to define access, which include everything from the system to the household, should also be used to monitor access to drinking water and evaluate water supply interventions. Multiple factors that were found to be directly related to accessibility, quantity and quality remains generally omitted in national households' survey although essential to generate realistic estimate, including: seasonality, proximity, reliability and post-collection contamination. Guidelines for standardized indicators and methods to monitor access to water should be discussed with all actors that are involved in the implementation of drinking water system in low-and middle-income countries, including governments, private sector, non-governmental organization (NGO) and international organization (IO).

Limitations

In addition to the limitations stated for each chapter, overall limitations that relate to the study area, methodology, methods and research process should be acknowledged.

This study was conducted in Malawi in three different sites selected as part of the case study. Although this research provided detailed information, the site-specific findings cannot, yet, be extrapolated to the country as a whole nor widely to low- and middle-income countries. More studies are necessary to generalize the results to other countries. Important differences were observed between rural and urban areas, and between rainy and dry seasons (Chapter 4-5), which highlight the contextual importance when assessing and monitoring access to drinking water. Results from this study, however, helped to frame recommendations to assess and monitor access to drinking water that are generalizable globally. The methodology used in this study can be scaled up and this would be recommended. This study yields multifold insights for future research including regarding the potential of conducting similar research in other settings and countries.

Primary data was collected under a prospective cohort study design which allowed for the assessment of the impact of seasonality and explore the relationship between other water-related variables (Chapter 3-4-5). It should be stated that households included in this seasonal cohort study were only visited twice, once during the rainy season and once during the dry season. To the best of my knowledge, this is the first study assessing the use of multiple water sources using a cohort study design rather than a cross-sectional study using prospective/retrospective information. Financial and temporal constraints, however, did not allow for the follow up of households further in length or frequency. Similarly, the total sample from the baseline (n = 375) was subsequently reduced into a subsample for the follow-up (n = 115) to allow for a more in depth study on water quality and post collection contamination along with seasonal variations. Households were selected randomly at the baseline using field based methods (i.e., sampling house interval using directions from central geographical locations) due to the lack of sampling frame available. The selected method was based on the WHO EPI-sampling method that is commonly used in low-and middle-income countries where sampling can be challenging (WHO/UNICEF 2017a). The potential selection bias attributable to this method should be noted, but it is expected that the effect would be minimal as enumerators were trained to limit such bias. Households included in the subsample were randomly selected among all households and this was done for each site to ensure geographical representativeness. Households were revisited using geolocalisation of the households (i.e., household coordinates) along with the name of the participant. No problem with attrition was noted during the second visit. If households were not available or absent, another household from the sample was randomly selected, which simplified data collection whilst ensuring representativeness.

It should also be stated that the methods used in this cohort study may have been subject to different misclassification bias. Most of the data was collected through questionnaires and represent self-reported information that is subject to recall bias. Appraising the reliability of self-reported measure with regard to access to water (Chapter 3), allowed for the validation of its accuracy to estimate global estimates; which is expected to overcome potential associated bias. The use of methods such as observations and GPS-based measurements allowed for the exploration of alternatives to self-reported measurements, but those were also subject to different limitations. Observations can result in biases from the participants (i.e., response bias) but also from the enumerator (i.e., researcher bias), and this was discussed during the enumerators' training to minimize such effect.

In addition to potential misclassification bias, certain limitations attributable to water quality testing should be highlighted. Water quality testing was performed on site using the low-cost filtration test. The use of reusable materials, i.e., funnels, was part of a low-cost field-testing component conducted in parallel with this study during the first visit. Results from blank testing - processing sterilized blank water- show higher rate of false positives than expected. A geometric mean of < 1 CFU *E. coli* was found for all blank tests, among which positive blank tests produced a geometric mean of 3 CFU *E. coli* (Zimmer 2019). As a result, the effect of misclassification bias is more likely to be greater on samples in the very low or low risk categories, where higher incidence of non-zero results for *E. coli* was found. Additionally, Whirl Pak bags without a dechlorinating agent were used, and this should be considered an important limitation for assessing water quality of the water sampled from water sources supplied by Blantyre water board network considering chlorine residual may have been found. Aside from the methods, the use of *E. coli* as an indicator of water quality is disputable. Using *E. coli* to assess water quality only infers that pathogens may or not be present, but doesn't allow for the identification of other coliforms, pathogens (e.g., virus, protozoa) or chemical forms and strains that are also recognized as potential threat for health (Fewtrell and Bartram 2001, Mara and Feachem 1999, Tallon et al. 2005). Despite its limitations for water quality assessment, *E. coli* remains, up-to-date, the most reliable indicator to identify risks of contamination (Fewtrell and Bartram 2001, Tallon, Magajna et al. 2005, Standridge 2008, Levy, Nelson et al. 2012, Gruber et al. 2014).

Enumerators that were hired for data collection had relevant background and experience, and were thoroughly trained for enumerations and water quality testing. A total of 6 enumerators were hired during the first visit, among which 4 were also available for reappointment in the second visit. Two additional enumerators were hired and integrated to the team for the second visit, along with one lab technician who helped with water quality testing. The training, based on MICS surveys guidelines and instructions (UNICEF 2019a) for conducting interviews, lasted 5 days as is typical in MICS trainings and covered all aspects of the project, guidelines and expectations, data collection, conducting questionnaires, along with water quality testing. The enumerators' work has been monitored to ensure consistency all along fieldwork. Although the importance of this project was stated, during the second visit, it was ascertained that one enumerator was conducting very short interviews (i.e., based on average interview time recorded on the tablet) which suggested a high likelihood that the enumerator was falsifying data. The enumerator did not confirm, but agreed to be dismissed. As a result, the data collected by the enumerator was removed (n = 30) from final analysis to ensure data integrity.

Finally, climate and political events that occurred during the duration of this cohort study may have had an influence on findings reported. The first visit was held in April 2019, two weeks after cyclone Idai (intense tropical cyclone, category 3 hurricane) hit Mozambique, Malawi and Zimbabwe, and lead to flooding, hundreds of deaths, and massive destruction. It is likely that this extreme event may have had an impact on households' behaviours in accessing drinking water, water provision and water quality, but such an effect remains unknown. Furthermore, a Malawian general election took place in May 2019, which may have influenced the water supply situation (e.g., willingness to provide water in view of the election) and households self-reported information (e.g., hope for change) during the first visit. The May 2019 election results were later disputed in widespread protests around the country, and this was undergoing during the second visit which was held in September 2019. Aside from logistical inconveniences, it is possible that the political situation influenced results from this study, but such impacts were beyond the scope of this research. Conducting fieldwork in low-and middle-income countries is subject to unforeseeable conditions, which requires close guidance, monitoring and, when necessary, readjustment. It should be stated that fieldwork was done, whereas climate and political events occurred in the country, following appropriate risk assessments, consultations with locals and ethical assessments were made. If any of the field visits had been delayed or postponed to 2020, none of this would have taken place due to COVID-19 pandemic and global disruptions.

Future Research

Future research may arise from the findings and limitations of this study. First, expanding methods and models used in this research in other countries with similar or different geographical settings would allow for the generalizability of the findings to be assessed. It is expected that results from this study may be extrapolated to other similar communities (e.g., water sources off premises, population density, type of settlements, similar climate). Results are generally similar to what have been previously published in the literature. Careful attention should however be held towards cultural differences that may be found in households' preferences in accessing drinking water. Second, integrating additional microbial components and chemical contaminants for water quality testing from the point of collection to the point of consumption would improve accuracy of the indicator and improve reliability of findings with regards to post-collection contamination. Introducing additional points of testing such as different containers and/or tools would also be valuable to study the extent of post-collection contamination. Third, conducting longitudinal research building on findings from this study would also be relevant to study the effect of climate change and extreme events on households' behaviours in accessing drinking water. Prospectively collecting data in the same cohort of households would allow for the exploration of monthly and annual changes in households fetching water practice and water source reliability, which remains understudied but essential to assess where efforts should be made in order to improve access to water. Furthermore, this would allow for the integration of geographical and meteorological components to better understand the impact of the environment. Finally, exploring the potential of developing and implementing water safety plans for household management in contexts where water fetching is common has not yet adequately been addressed and would be of interest to integrate components such as accessibility, quantity and quality with respect to seasonality and water source reliability.

Conclusions

This study added to the body of knowledge through original evidence-based research. Access to drinking water was explored through monitoring and assessment perspectives, which are both interrelated. The overall contributions of this research were: a systematic review of the literature with regards to water accessibility; an exploration of available data on water accessibility (in Malawi); to propose field-tested indicators and alternative methods to monitor access to drinking water; to assess the extent of post-collection contamination; while controlling for seasonality, to better understand interlinkages between access (i.e. accessibility, quantity, quality) and water source reliability; and to assess household's preferences and behaviours in accessing drinking water in settings without access to water on premises.

It is expected that results from this study will lead to more realistic estimations, suitable interventions and appropriate responses to needs in view of achieving universal and equitable access to safe and affordable drinking water by 2030, as targeted in the Sustainable Development Goal. It is hoped that relevant research findings will be integrated in national and international policy to support water supply monitoring efforts and interventions, and considered by NGO in view of targeting appropriate response to needs.

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Annexes

Annexe A. Sample Size and Household Selection

Sample size

Sample size was calculated using the following formula, using a 95% confidence level.

Equation A. 1. Sample size

$$Sample\ size = \frac{\frac{z^2 \times p\ (1-p)}{e^2}}{1 + \left(\frac{z^2 \times p\ (1-p)}{e^2 N}\right)}$$

where

$N = population\ size$

$e = margin\ of\ error$

$z = z - score$

$p = prior\ judgment\ value\ of\ sample\ population$

With large populations in each site, a minimum sample size of 300 households was targeted for the baseline. A total of 375 households were included at the baseline, with a calculated margin of error of 5%. Households were equally distributed with a total of 115 households per site at the baseline. A minimum of 96 households were aimed for the subsample (follow-up) to fall below the margin of error of 10%. The subsample finally included a total of 115 households equally distributed across sites, with 38 or 39 households per site.

Table A. 1. Sample size (n) at the baseline and follow-up, including margin of error and confidence level.

	Baseline	Follow-up
Sample	n =375	n = 115
Margin of error	5%	9%
Confidence level	95%	

Household selection

Baseline

Households were randomly selected at the baseline using field based methods due to the lack of sampling frame available. The selected method was based on WHO EPI-sampling method that is commonly used in low-and middle-income countries where sampling is challenging (WHO/UNICEF 2017a).

The method used in this study was based on a five-step approach:

1) Three study sites were selected, including two informal settlements located in urban/peri-urban areas and one rural site.

2) Four central locations were identified in each site based on size and geographical boundaries. From this point, enumerators were divided in pairs and directed through straight opposite directions.

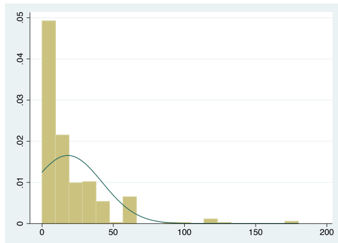
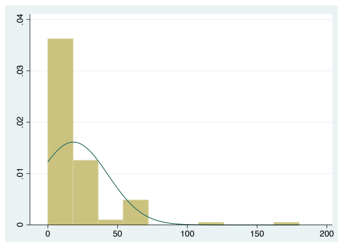
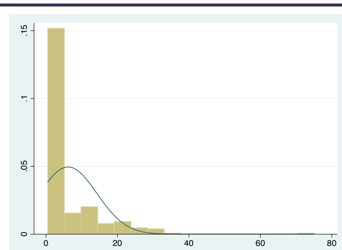
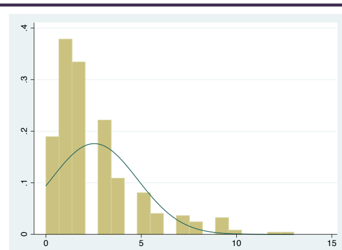
4) Enumerators walked in pairs until they have reached the first water source which was considered as a starting point for sampling. Enumerators walk outwards from the source along the two-opposite directions which were randomly selected by spinning a pen or a bottle.

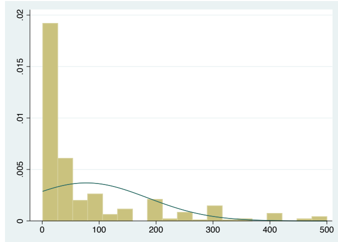
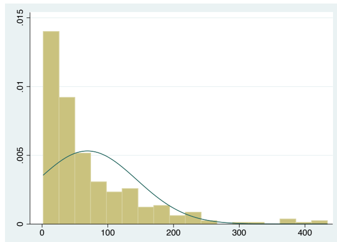
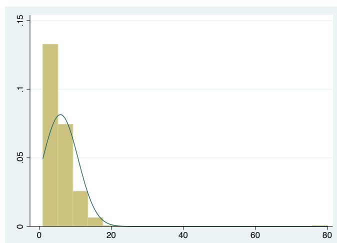
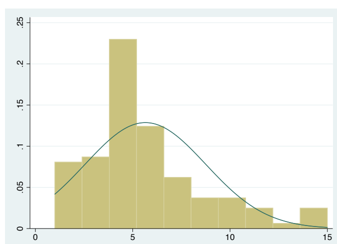
5) Households were selected in a straight direction according to a sampling interval (i.e., 10^{th} – 5^{th} – 2^{nd} closest right-handed house) which was determined based on the sites' densities. The enumerators followed the right-handed side of the road in cases where road crossed.

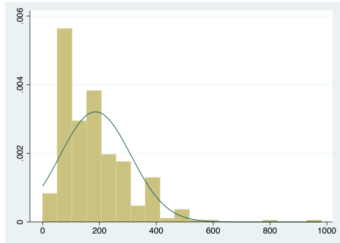
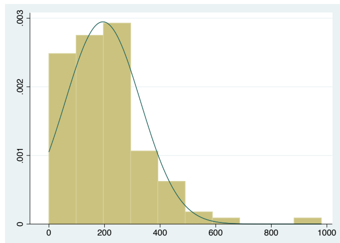
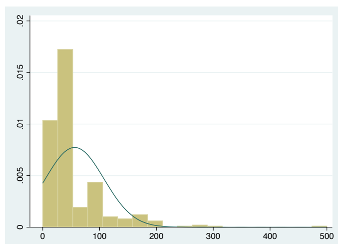
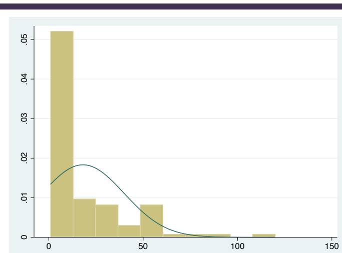
Follow-up

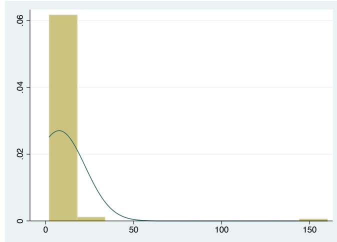
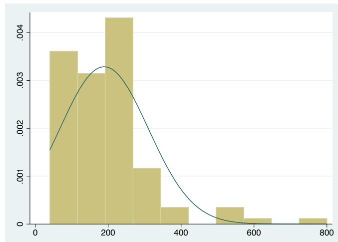
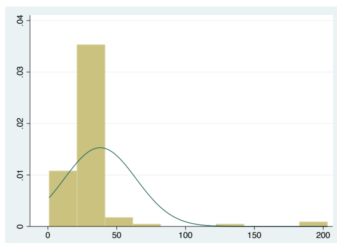
Households included in the subsample for follow-up were randomly selected within the list of households initially visited in each site. Overall, 50 households per site where withdraw from the sample and listed for the follow-up. Enumerators were required to visit the households in order until they reach a certain number of households per day. When households were not available, the enumerator was visiting following households on the list. A total of 115 households were finally included in the subsample.

Annexe B. Normality Test

Variables		Graphical representation of the distribution	Obs. (missing)	Min.	Max.	Mean	Std. Dev.	Skewness	Kurtosis
Rainy	Round-trip collection time (minutes)		373 (2)	0	180	18.11	24.11	3.18	16.93
	subsample		115	0	180	18.30	24.73	3.42	19.46
	One way collection time (minutes)		276	0.5	75	6.21	8.06	3.41	22.62
	One way recorded time (minutes)		363	0	13	2.54	2.67	1.53	5.64

One way estimated distance (meters)		363	1	500	77.31	107.98	1.96	6.31
One way GPS distance (meters)		339	1.78	434.06	68.99	75.05	2.11	8.52
Daily trip frequency water collection *subsample*		375	1	80	5.89	4.90	9.54	141.34
		115	1	15	5.65	3.10	1.14	4.24

	Daily quantity collected (litres)		375	0	980	186.2	124.34	1.66	8.31
	subsample		115	0	980	194.2	135.35	2.22	11.87
	Quantity collected each trip (litres)		375	0	500	56.07	51.60	3.26	20.24
Dry	Round-trip collection time (minutes)		113 (2)	1	120	18.14	21.77	1.96	7.24

Daily trip frequency water collection		115	2	160	7.6	14.76	9.70	100.65
Daily quantity collected (litres)		113 (2)	40	800	188.76	121.42	1.99	9.08
Quantity collected each trip (litres)		115	1	203	38	26.08	4.84	29.89

Annexe C. Statistical analysis

Manuscript 3. Evaluating self-reported measures and alternatives to monitor access to drinking water: Evidence from a case study in Malawi

Variables				Statistical Analysis
V1	Type	V2	Type	
Daily quantity reported (litres)	(continuous)	Household size (n)	(continuous)	Spearman's Rank Correlation (r_s)
		Trip frequency * quantity per trip (litres)	(continuous)	Wilcoxon Signed-Rank test
Water source microbial water quality (level of risk)	(ordinal)	Drinking cup microbial water quality (level of risk)	(ordinal)	Fisher's exact test
		Perception of the water quality	(ordinal)	Fisher's exact test
		Perception – Water already clean	(binary)	Fisher's exact test
Drinking cup microbial water quality (level of risk)	(ordinal)	Perception of the water quality	(ordinal)	Fisher's exact test
		Perception – Water already clean	(binary)	Fisher's exact test
Type water treatment	(nominal)	Drinking cup microbial water quality (level of risk)	(ordinal)	Fisher's exact test
		Perception water quality	(ordinal)	Fisher's exact test
Self-reported collection time (minutes)	(continuous)	Recorded walking time (meters)	(continuous)	Spearman's Rank Correlation (r_s) - Correlation Matrix
		Euclidean distance (meters)	(continuous)	
		Walking distance (meters)	(continuous)	

Manuscript 4. Drinking water accessibility and post collection contamination: A seasonal cohort study in Malawi

Variables				Statistical Analysis
V1	Type	V2	Type	
Water source microbial water quality (level of risk)	(ordinal)	Location (urban/rural)	(nominal)	Chi-square test of independence (x^2)
Rainy - Water source microbial water quality (level of risk)	(ordinal)	Dry - Water source microbial water quality (level of risk)	(ordinal)	Spearman's Rank Correlation (r_s)

Rainy – Drinking cup microbial water quality (level of risk)	(ordinal)	Dry - Drinking cup microbial water quality (level of risk)	(ordinal)	Spearman's Rank Correlation (r_s)
Rainy - Water source microbial water quality (level of risk)	(ordinal)	Rainy – Drinking cup microbial water quality (level of risk)	(ordinal)	Spearman's Rank Correlation (r_s)
Dry –S1 water quality (level of risk)	(ordinal)	Rainy –S2 water quality (level of risk) Rainy –S3 water quality (level of risk) Rainy –S4 water quality (level of risk)	(ordinal)	Spearman's Rank Correlation (r_s) - Correlation Matrix
Critical points of contamination – self-reported	(nominal; binary)	Critical points of contamination – observations	(nominal; binary)	Descriptive statistics. Measure of agreement – Kappa coefficient
Presence of E.coli (presence or absence)	(binary)	Factors of risk (e.g., location household, type of water source, collection containers, storage containers, water treatment, rainwater collection, standing water use, hygiene and sanitation)	(nominal; binary)	Chi-Square Test of Independence (x^2)
Change level of risk water quality (same quality, improvement, degradation)	(nominal)	Factors of risk (e.g., location household, type of water source, collection containers, storage containers, water treatment, rainwater collection, standing water use, hygiene and sanitation)	(nominal; binary)	Chi-Square Test of Independence (x^2)

Manuscript 5. Household preferences in accessing multiple drinking water sources

Variables				Statistical Analysis
V1	Type	V2	Type	
Rainy – Multiple water sources	(ordinal)	Dry – Multiple water sources	(ordinal)	Wilcoxon Signed-Rank test
Rainy – Type of water source	(nominal)	Dry - Type of water source (dry)	(nominal)	Chi-Square Test of Independence (x^2)
Rainy – Multiple water sources	(ordinal)	Location (urban/rural)	(binary)	Chi-Square Test of Independence (x^2)
		Water source microbial water quality (level of risk)	(ordinal)	Chi-Square Test of Independence (x^2)
Dry – Multiple water sources		Drinking cup microbial water quality (level of risk)	(ordinal)	Chi-Square Test of Independence (x^2)
		Willing to walk for better quality	(binary)	Chi-Square Test of Independence (x^2)

		Would collect more water if source was located closer	(binary)	Chi-Square Test of Independence (x^2)
		Pay for water at primary source	(binary)	Chi-Square Test of Independence (x^2)
Rainy - Self-reported collection time (minutes) Dry - Self-reported collection time (minutes)	(continuous)	Multiple water sources	(ordinal)	Kruskal-Wallis H Test
		Water source microbial water quality (level of risk)	(ordinal)	Kruskal-Wallis H Test
		Drinking cup microbial water quality (level of risk)	(ordinal)	Kruskal-Wallis H Test
		Trip frequency	(continuous)	Spearman's Rank Correlation (r_s)
Rainy - Daily quantity reported (litres) Dry - Daily quantity reported (litres)	(continuous)	Multiple water sources	(ordinal)	Kruskal-Wallis H Test
		Collection time	(continuous)	Spearman's Rank Correlation (r_s)
		Trip frequency	(continuous)	Spearman's Rank Correlation (r_s)
		Water source microbial water quality (level of risk)	(ordinal)	Kruskal-Wallis H Test
		Drinking cup microbial water quality (level of risk)	(ordinal)	Kruskal-Wallis H Test
Rainy - Daily quantity reported (litres)	(continuous)	Dry - Daily quantity reported (litres)	(continuous)	Wilcoxon Signed-Rank test
Multiple water sources (single/multiple)	(binary)	Predictors of use (accessibility, quantity, quality)	(binary and continuous)	Binary logistic regression

Annexe D. Household Questionnaire I

SECTION 1. GENERAL INFORMATION	
Interviewer's name and number : ______________________ ID______	Date (dd/mm/year) : ______/______/____________
Study site : ☐ Site 1 – Peri-urban - Blantyre (Ndirande) ☐ Site 2 – Peri-urban - Blantyre (Mbayani) ☐ Site 3 – Rural - Chikwawa	Household location (coordinates): _______________ | _______________ Household number (HHID) : _____ _____ _____ _____
Record start time (hour : minutes) ________ : ________	

SECTION 2. PARTICIPANT INFORMATION		
Respondent name: ____	Age: _____________ y/o	Sex: F ☐/M ☐
What is your relationship to the head of the household:	Head .... 1 Spouse/partner .... 2 Son/Daughter .... 3 Son-in-law/Daughter-in-law ..... 4 Grandchild .... 5 Parent .... 6 Parent-in-law .... 7 Brother/Sister .... 8 Brother-in-law/Sister-in-law ... 9 Uncle/Aunt .... 10 Niece/Nephew .... 11 Other *(specify)* 96	
What is the highest level and grade or year of school the head of the household have ever attended?	No education.................... 0 Primary......................... 1 Secondary....................... 2 Higher.......................... 3 Don't know...................... 10	
Who usually collect the water for your household ?	Head .... 1 Spouse/partner .... 2 Son/Daughter .... 3 Son-in-law/Daughter-in-law ..... 4 Grandchild 5	

	Parent .... 6 Parent-in-law .... 7 Brother/Sister .... 8 Brother-in-law/Sister-in-law ... 9 Uncle/Aunt .... 10 Niece/Nephew .... 11 Other *(specify)* 96

SECTION 3. HOUSEHOLD INFORMATION	
Including yourself, how many people live in this household ?	Number of people: ________________
Does your household have electricity ?	Yes .... 1 No .... 2 Don't know 98
Does your household have access to internet at home ?	Yes .... 1 No .... 2 Don't know 98
Do you or any member of your household own a mobile phone ?	Yes .... 1 No .... 2 Don't know 98
Does any member of your household own: A bicycle A motorcycle or scooter An animal-drawn cart A car, truck or van	 Yes .... 1 No .... 2 Yes .... 1 No .... 2 Yes .... 1 No .... 2 Yes .... 1 No .... 2 Don't know 98
Does this household own any livestock, herds, other farm animals, or poultry?	Yes .... 1 No 2

	Don't know 98

SECTION 4. HYGIENE	
Where members of your household **most often** wash their hands ?	**FIXED FACILITY** Sink/tap in dwelling ....1 Sink/tap in the yard or plot .....2 **MOBILE** Bucket/jug/kettle/basin ....3 No handwashing place 4
Is there always water available for hand washing ?	Yes ....1 No ....2 Don't know 98
Do you have any soap or detergent or ash/mud/sand in your house for handwashing?	Yes ....1 No ....2 Don't know 98
Where do you most often shower or bath?	At home ....1 In the river/surface water ....2 Elsewhere 3
Where do you most often wash your clothes?	At home ....1 In the river/surface water ....2 Elsewhere 3

SECTION 5. SANITATION	
What kind of toilet facility do members of your household **usually** use? *If 'Flush' or 'Pour flush', probe:* Where does it flush to? *Use pictorials*	**FLUSH / POUR FLUSH** Flush to piped sewer system .....11 Flush to septic tanks ....12 Flush to pit latrine ....13 Flush to open drain ....14 Flush to - don't know ....18 **PIT LATRINE** Ventilated improved pit ....21 Pit latrine with slab ....22 Pit latrine without slab/open ...23 Composting toilet 31

	Bucket .... 41 Hanging toilet/latrine .... 51 No facility/bush/field .... 95 Other (*specify*) _________________ 96
Where is this toilet facility located?	In own dwelling .... 1 In own yard / plot .... 2 Elsewhere 3
How long does it take for members of your household to go to the toilet? *(Record in minutes)*	Time (minutes) ____ ____ ____
Is this facility always available for use?	Yes .... 1 No 2
Is this facility used by all members of your household, including children?	Yes .... 1 No 2
Do you share this facility with other who are not members of your household?	No .... 1 Yes, w/ household members .... 1 Yes, w/ known people .... 2 Yes, w/ public (unknown people) .. 3 Other (*specify*) 96

SECTION 6. WATER	
6.1 Primary water source	
What is the **main** source of drinking water used by members of your household? *The place from which members of this household most often collect drinking water.* *If 'piped' probe:* *Where is it piped?*	**PIPED WATER** Piped to yard / plot .... 12 Piped to neighbour .... 13 Public tap / standpipe .... 14 Tube well / borehole .... 21 **DUG WELL** Protected well .... 31 Unprotected well .... 32 **SPRING**

Use pictorials	Protected spring .... 41 Unprotected spring .... 42 Rainwater .... 51 Tanker-truck .... 61 Cart with small tank .... 71 Water kiosk .... 72 Surface water (river, dam, lake, pond, stream, canal, irrigation channel) .... 81 **PACKAGED WATER** Bottled water .... 91 Sachet water .... 92 Other *(specify)*_________________96
Why do you use this source as your primary source of drinking water?	Closest source .... 1 Waiting time is the shortest ... 2 Water taste is the best .... 3 Water is safe/clean .... 3 Water is always available ...... 4 Water is free .... 5 There is no other source ...... 95 Other *(specify)*_________________ 96
Where is this source located?	In own dwelling .... 1 In own yard/plot .... 2 Elsewhere 3
Is water available throughout the year?	Yes............................. 1 No.............................. 2
Do you use this source all year long?	Yes............................. 1 No.............................. 2
How long does it take for members of your household to go there, get water, and come back? How long are you/other members wait in a queue at the source?	Time (minutes) ____ ____ ____ Waiting time (minutes) ____ ____ ____

Is this source the closest source from your dwelling?	Yes....1 No....2 Don't know....98
Is the quantity of water that you receive from this source adequate for drinking, hygiene, cleaning and cooking ?	Yes....1 No....2
Do you have to pay to get water from this source?	Yes....1 No....2
Is there any other source of water used by your household? *If 'no' skip sections 6.2 and 6.3.*	Yes....1 No....2
6.2 Secondary water Source	
What is the **second** source of water used by members of your household? *If 'piped' probe:* *Where is it piped?* *Use pictorials*	**PIPED WATER** Piped to yard / plot....12 Piped to neighbour....13 Public tap / standpipe....14 Tube well / borehole.... 21 **DUG WELL** Protected well....31 Unprotected well....32 **SPRING** Protected spring....41 Unprotected spring....42 Rainwater....51 Tanker-truck....61 Cart with small tank ....71 Water kiosk....72 Surface water (river, dam, lake, pond, stream, canal, irrigation channel) ....81 **PACKAGED WATER** Bottled water....91 Sachet water....92 Other *(specify)*______________ 96

Where is this water source located?	In own dwelling ....1 In own yard / plot ....2 Elsewhere 3
How long does it take for members of your household to go there, get water, and come back? *(Record in minutes)* How long are you/other members wait in a queue at the source? *(Record in minutes)*	Time (minutes) ___ ___ ___ Waiting time (minutes) ___ ___ ___
Do you have to pay to get water from this source?	Yes ....1 No 2
When do you use the second source of water instead of the first source ?	Water is not running ....1 Source is broken ....2 Water is too expensive ....3 Source is too far ....4 Source is not accessible ....5 Need more water ....6 Don't need good water quality ....7 *(e.g. bathing, gardening)* Other *(specify)*_______________ ..96
Approximately how many times do you use the second source in a week?	Always use both (7 days) ....1 Mostly (5-6 days) ....2 Sometimes (3-4 days) ....3 A few times (1-2 days) ....4 Never ....4 Other *(specify)*_______________ ..96
Is there any other source of water used by your household? *IF 'NO' SKIP SECTION 6.3.*	Yes ....1 No 2
6.3 Tertiary water source	
What is the **third** source of water used by members of your household? *If 'piped' probe:* *Where is it piped?*	**PIPED WATER** Piped to yard / plot ....12 Piped to neighbour ....13 Public tap / standpipe ....14 Tube well / borehole 21

Use pictorials	**DUG WELL** Protected well.................31 Unprotected well...............32 **SPRING** Protected spring...............41 Unprotected spring.............42 Rainwater......................51 Tanker-truck...................61 Cart with small tank ....71 Water kiosk....................72 Surface water (river, dam, lake, pond, stream, canal, irrigation channel).....................81 **PACKAGED WATER** Bottled water..................91 Sachet water...................92 Other *(specify)*_______________ 96
Where is that water source located?	In own dwelling.................1 In own yard / plot..............2 Elsewhere.......................3
How long does it take for members of your household to go there, get water, and come back? How long are you/other members wait in a queue at the source?	Time (minutes) ___ ___ ___ Waiting time (minutes) ___ ___ ___
When do you use the second source of water instead of the first source?	Water is not running.............1 Source is broken.................2 Water is too expensive...........3 Source is too far................4 Source is not accessible.........5 Need more water ....6 Don't need good water quality....7 *(e.g. bathing, gardening)* Other *(specify)*_______________..96
Approximately how many times do you use the second source in a week?	Always use both (7 days).........1 Mostly (5-6 days)................2

	Sometimes (3-4 days) ....3 A few times (1-2 days) ....4 Never ....4 Other *(specify)*_______________ ..96

6.4 Seasonality	
In general, do you **usually** use the same water sources during the rainy season and the dry season?	Yes ....1 No ....2 Don't know 98
In the rainy season, do you **usually** collect rainwater?	Yes ....1 No ....2 Don't know 98
In general, do you collect and use standing water in or around your dwelling?	Yes ....1 No ....2 Don't know 98
Do you ever collect water in the river or from any other source of surface water?	Yes ....1 No ....2 Don't know 98
6.4 Water collection	
Would you collect more water if a new source was located closer to your household?	Yes ....1 No ....2 Don't know 98
Would you be keen to walk further to collect a greatest quality of water?	Yes ....1 No ....2 Don't know 98
How many people usually collect water for your household?	Only myself ....1 One person (someone else) ....2 Two people ....3 More than 2 people 4
Do you or someone else need to collect water **each day** for your household?	Yes ....1 No 2

	Don't know 98
How many trips do you [or water fetcher] **usually** make in a day?	Number of trips: ___ ___
How much time do you [or water fetcher] **usually** make in a day? *(Record in minutes)*	Time (minutes): ___ ___ ___
How water is usually carried by water fetchers?	Head, back or hands ....1 Rolling ....2 Wheel barrows ....3 Animal drawn, motorcycle or car..4 Yoke ....5 Other *(specify)* ________________96 Don't know 98
What are the containers used to collect water? *Record all items* *Use pictorials* *Probe 'Can you show me the containers?'*	Jerrycan ....1 Bucket ....2 Pot without handles ....3 Metal bucket ....4 Rolling container ....5 Other *(specify)* ....96 Don't know ....98 Yes, shown ....1 Not shown 2
6.5 Water quantity	
What is, **approximately**, the quantity of water collected each time someone goes to the source? *(Record in litres)*	Litres: ___________
How many containers do you [or water fetcher] usually bring to collect water?	Number of containers: ___ ___
What is, **approximately**, the total quantity of water collected each day? *(Record in litres)*	Litres: ___________
Do you consider this is enough to meet household needs?	Yes ....1 No 2
Which personal or domestic purpose required the greatest quantity of water ?	Drinking (household members) .....1 Cooking 2

	Handwashing ....3 Bathing/Showers ....4 Cleaning the house ....5 Washing clothes ....6 Feeding animals ....7 Other *(specify)* __________________96 Don't know 98
In the last week, has there been any time when your household did not have sufficient quantities of water, including for hygiene and cleaning?	Yes, at least once ....1 No, always sufficient ....2 Don't know 98
When quantities of water are not sufficient, which personal or domestic purpose is the most important for you? Drinking, cooking, handwashing, bathing or feeding animals.	Drinking (household members) .....1 Cooking ....2 Handwashing ....3 Bathing/Showers ....4 Cleaning the house ....5 Washing clothes ....6 Feeding animals ....7 Other *(specify)* __________________96 Don't know 98
6.5 Water storage	
Once you come back from collecting water, do you use another storage facility?	Yes (Use storage) ....1 No (Leave water in the container) 2
Where do you store the water? *Probe 'Can you show me the principal water storage container?'*	Jerrycan ....1 Covered bucket ....2 Uncovered bucket ....2 Pot without handles ....3 Metal container ....4 Other *(specify)* ....96 Don't know ....98 Yes ....1 No 2

Record estimated volume of the storage container (litres)	Litres: ___________
6.7 Water treatment	
Do you or any other member of this household do anything to the water to make it safer to drink?	Yes ....1 No ....2 Don't know 98
What do you usually do to make the water safer to drink?	Boil ....1 Add bleach / chlorine ....2 Strain it through a cloth ....3 Use water filter ....4 Solar disinfection ....5 Let it stand and settle ....6 Other (*specify*) _________________96 Don't know 98
Why don't you do anything to make the water safer to drink?	Water is already clean/safe ......1 It is too complicated ....2 It is not important ....3 It is too expensive ....4 It takes too long ....5 Don't know how ....6 Other (*specify*) _________________96

SECTION 7. WATER QUALITY TESTING	
7.1 Household sampling	
Is the household selected for blank testing	Yes ☐ No ☐
Could you please provide me with a glass of the water that members of your households would drink?	Yes .... 1 No 2
Record where the water comes from	Jerrycan .... 1 Covered bucket w/ tap .... 2 Covered bucket w/o tap 2

	Uncovered bucket w/ tap .... 3 Uncovered bucket w/o tap .... 3 Pot .... 4 Metal container .... 4 Bottle(s) .... 4 Other (*specify*) ________________ 96 Couldn't observed 99
Label sample H-HHID, date, time *Conduct test within 30 minutes of collecting sample.* *Record the result following incubation*	
If the household is selected for blank testing: *Take out the sample of sterile/mineral water.* *Conduct blank testing*	Blank water sample available .... 1 Blank water sample not available . (Specify) 2
Label sample B-HHID, date, time *Conduct test within 30 minutes of collecting sample.* *Record the result following incubation*	
What source was this water collected from?	**PIPED WATER** Piped to yard / plot .... 12 Piped to neighbour .... 13 Public tap / standpipe .... 14 Tube well / borehole .... 21 **DUG WELL** Protected well .... 31 Unprotected well .... 32 **SPRING** Protected spring .... 41 Unprotected spring .... 42 Rainwater .... 51 Tanker-truck .... 61 Cart with small tank .... 71 Water kiosk 72

	Surface water (river, dam, lake, pond, stream, canal, irrigation channel) .... 81 **PACKAGED WATER** Bottled water .... 91 Sachet water .... 92 Other *(specify)*_______________ 96
Overall, what is your perception on the water quality of this sample?	Excellent .... 1 Good - Neutral .... 2 Poor 3
Have you or any other member of this household done anything to this water to make it safer to drink?	Yes .... 1 No 2
If yes → What has been done to the water to make it safer to drink?	Boil .... A Add bleach / chlorine .... B Strain it through a cloth .... C Use water filter .... D Solar disinfection .... E Let it stand and settle .... F Other (*specify*) _________________ x Don't know 98
Which characteristic is the most important when drinking water: taste, colour, odour or quality/safety?	Taste .... 1 Colour .... 2 Odour .... 3 Quality .... 4 Nothing in particular .... 4 Other *(specify)*________________ 96
7.2 Source Sampling	

Can you please show me the source of the glass of drinking water so that I can? - take a sample from there? - record the localisation of the source - track the path and measure the distance *If 'No' probe to find out why this is not possible*	Yes .... 1 No, not functional .... 2 No, too far .... 3 No, unable to access .... 4 Other (*specify*) .... 98 Don't know where the source is . 98
Record departure time	______ : _______
Record arrival time	______ : _______
Record location of the water source (coordinates)	___ ___ ___ ___ | ___ ___ ___ ___
Record estimated distance between the dwelling and the water sources (meters)	Distance:__________ meters
Take a photo of the water source	
Label sample S-HHID, date, time *Conduct test within 30 minutes of collecting sample.* *Record the result following incubation*	

8. Contact information	
Do you agree being re-contacted for a follow-up?	Yes .... 1 No 2
What is your phone number?	+ 265 _________________
Record end time: ______:______	

[This form was adapted from Multiple Indicator Cluster Survey (MICS) Household Questionnaire and Water Quality Testing Questionnaire]
Author: Cassivi Alexandra
Last update: 21/04/2020

Annexe E. Household Questionnaire II

SECTION 1. GENERAL INFORMATION	
Interviewer’s name and number : _______________________ ID______	Date (dd/mm/year) : ______/______/____________
Study site : ☐ Site 1 – Peri-urban - Blantyre (Ndirande) ☐ Site 2 – Peri-urban - Blantyre (Mbayani) ☐ Site 3 – Rural - Chikwawa	Household location (coordinates): _______________ | _______________ Household number (HHID) : _____ _____ _____ _____ Confirm this is the same household with consent form : Yes ☐/No ☐ **Only survey households that consented for a follow-up.No new households should be surveyed at this point.*
Record start time (hour : minutes) ________ : ________	

SECTION 2. PARTICIPANT INFORMATION		
Respondent name: ____	Age: _____________ y/o	Sex: F ☐/M ☐
What is your relationship to the head of the household:	Head .... 1 Spouse/partner .... 2 Son/Daughter .... 3 Son-in-law/Daughter-in-law ..... 4 Grandchild .... 5 Parent .... 6 Parent-in-law .... 7 Brother/Sister .... 8 Brother-in-law/Sister-in-law ... 9 Uncle/Aunt .... 10 Niece/Nephew .... 11 Other *(specify)* 96	
What is the highest level and grade or year of school the head of the household have ever attended?	No education.................... 0 Primary......................... 1 Secondary....................... 2 Higher.......................... 3	

	Don't know........................10
Are you usually collect the water for your household ?	Yes...............................1 No................................2

SECTION 3. HYGIENE	
Where members of your household **most often** wash their hands ?	**FIXED FACILITY** Sink/tap in dwelling.............1 Sink/tap in the yard or plot.....2 **MOBILE** Bucket/jug/kettle/basin..........3 No handwashing place.............4
Is there always water available for hand washing ?	Yes...............................1 No................................2 Don't know.......................98
Do you have any soap or detergent or ash/mud/sand in your house for handwashing?	Yes...............................1 No................................2 Don't know.......................98
Where do you most often shower or bath?	At home..........................1 In the river/surface water.......2 Elsewhere........................3
Where do you most often wash your clothes?	At home..........................1 In the river/surface water.......2 Elsewhere........................3

SECTION 4. WATER	
4.1 Primary water source	
What is the **main** source of drinking water used by members of your household? *The place from which members of this household most often collect drinking water.*	**PIPED WATER** Piped to yard / plot ....12 Piped to neighbour ....13 Public tap / standpipe ....14 Tube well / borehole 21

If 'piped' probe: *Where is it piped?* *Use pictorials*	**DUG WELL** Protected well .... 31 Unprotected well .... 32 **SPRING** Protected spring .... 41 Unprotected spring .... 42 Rainwater .... 51 Tanker-truck .... 61 Cart with small tank .... 71 Water kiosk .... 72 Surface water (river, dam, lake, pond, stream, canal, irrigation channel) .... 81 **PACKAGED WATER** Bottled water .... 91 Sachet water .... 92 Other *(specify)*_________________96
Why do you use this source as your primary source of drinking water?	Closest source .... 1 Waiting time is the shortest ... 2 Water taste is the best .... 3 Water is safe/clean .... 3 Water is always available ...... 4 Water is free .... 5 There is no other source ...... 95 Other *(specify)*_________________ 96
Where is this source located?	In own dwelling .... 1 In own yard/plot .... 2 Elsewhere 3
Is water available throughout the year?	Yes............................. 1 No.............................. 2
Do you use this source all year long?	Yes............................. 1 No.............................. 2
How long does it take for members of your household to go there, get water, and come back?	Time (minutes) ____ ____ ____

How long are you/other members wait in a queue at the source?	Waiting time (minutes) ____ ____ ____
Is this source the closest source from your dwelling?	Yes............................1 No.............................2 Don't know....................98
Is the quantity of water that you receive from this source adequate for drinking, hygiene, cleaning and cooking ?	Yes............................1 No.............................2
Do you have to pay to get water from this source?	Yes............................1 No.............................2
Is there any other source of water used by your household? *If 'no' skip sections 4.2 and 4.3.*	Yes............................1 No.............................2
4.2 Secondary water source	
What is the **second** source of water used by members of your household? *If 'piped' probe:* *Where is it piped?* *Use pictorials*	**PIPED WATER** Piped to yard / plot...........12 Piped to neighbour.............13 Public tap / standpipe.........14 Tube well / borehole.......... 21 **DUG WELL** Protected well.................31 Unprotected well...............32 **SPRING** Protected spring...............41 Unprotected spring.............42 Rainwater......................51 Tanker-truck...................61 Cart with small tank ....71 Water kiosk....................72 Surface water (river, dam, lake, pond, stream, canal, irrigation channel) ....81 **PACKAGED WATER** Bottled water..................91 Sachet water...................92

	Other *(specify)*________________ 96
Where is this water source located?	In own dwelling.................1 In own yard / plot..............2 Elsewhere.......................3
How long does it take for members of your household to go there, get water, and come back? *(Record in minutes)* How long are you/other members wait in a queue at the source? *(Record in minutes)*	Time (minutes) ___ ___ ___ Waiting time (minutes) ___ ___ ___
Do you have to pay to get water from this source?	Yes.............................1 No..............................2
When do you use the second source of water instead of the first source ?	Water is not running.............1 Source is broken.................2 Water is too expensive...........3 Source is too far................4 Source is not accessible.........5 Need more water ....6 Don't need good water quality....7 *(e.g. bathing, gardening)* Other *(specify)*________________ ..96
Approximately how many times do you use the second source in a week?	Always use both (7 days) ....1 Mostly (5-6 days) ....2 Sometimes (3-4 days) ....3 A few times (1-2 days) ....4 Never............................4 Other *(specify)*________________ ..96
Is there any other source of water used by your household? *IF 'NO' SKIP SECTION 4.3.*	Yes.............................1 No..............................2
4.3 Tertiary water source	
What is the **third** source of water used by members of your household?	**PIPED WATER** Piped to yard / plot...........12 Piped to neighbour.............13 Public tap / standpipe.........14

If 'piped' probe: *Where is it piped?* *Use pictorials*	Tube well / borehole .... 21 **DUG WELL** Protected well.................31 Unprotected well...............32 **SPRING** Protected spring...............41 Unprotected spring.............42 Rainwater......................51 Tanker-truck...................61 Cart with small tank ....71 Water kiosk....................72 Surface water (river, dam, lake, pond, stream, canal, irrigation channel) ....81 **PACKAGED WATER** Bottled water..................91 Sachet water...................92 Other *(specify)*________________ 96
Where is that water source located?	In own dwelling.................1 In own yard / plot..............2 Elsewhere.......................3
How long does it take for members of your household to go there, get water, and come back? How long are you/other members wait in a queue at the source?	Time (minutes) ___ ___ ___ Waiting time (minutes) ___ ___ ___
When do you use the second source of water instead of the first source?	Water is not running.............1 Source is broken.................2 Water is too expensive...........3 Source is too far................4 Source is not accessible.........5 Need more water ....6 Don't need good water quality....7 *(e.g. bathing, gardening)* Other *(specify)*________________..96

Approximately how many times do you use the second source in a week?	Always use both (7 days) ....1 Mostly (5-6 days) ....2 Sometimes (3-4 days) ....3 A few times (1-2 days) ....4 Never ....4 Other *(specify)*________________ ..96
4.4 Seasonality	
In general, do you **usually** use the same water sources during the rainy season and the dry season?	Yes ....1 No ....2 Don't know 98
In the rainy season, do you **usually** collect rainwater?	Yes ....1 No ....2 Don't know 98
In general, do you collect and use standing water in or around your dwelling?	Yes ....1 No ....2 Don't know 98
Do you ever collect water in the river or from any other source of surface water?	Yes ....1 No ....2 Don't know 98

5. Water collection	
5.1 Pre-collection	
How many people usually collect water for your household?	Only myself ....1 One person (someone else) ....2 Two people ....3 More than 2 people 4
Do you or someone else need to collect water **each day** for your household?	Yes ....1 No ....2 Don't know 98
How many trips do you [or water fetcher] **usually** make in a day?	Number of trips: ___ ___
How much time do you [or water fetcher] **usually** make in a day? *(Record in minutes)*	Time (minutes): ___ ___ ___

How water is usually carried by water fetchers?	Head, back or hands ....1 Rolling ....2 Wheel barrows ....3 Animal drawn, motorcycle or car ..4 Yoke ....5 Other *(specify)* _________________96 Don't know 98
What are the containers used to collect water? *Record all items* *Use pictorials*	Jerrycan ....1 Bucket ....2 Pot without handles ....3 Metal bucket ....4 Rolling container ....5 Other *(specify)* ....96 Don't know 98
Do you only use those container(s) for water collection?	Yes ....1 No 2
Where do you keep the collection container(s) when not in use? *If 'outside', probe:* *covered or uncovered?*	Inside the house ....1 Covered area outside the house ...2 Uncovered area outside the house .3
Do you use covered container(s) when carrying water?	Yes ....1 No 2
Do you use container(s) that are cracked or leaking?	Yes ....1 No 2
Do you use collection container(s) to : store any other liquids? store food or wood? wash clothes or dishes? hand wash?	 Yes ....1 No ....2 Yes ....1 No ....2 Yes ....1 No ....2 Yes ....1 No 2

wash babies/kids?	Yes ....1 No 2
store agricultural pesticides or products?	Yes ....1 No 2
any other purpose?	Yes:____________________________ ..1 No 2
How many containers do you [or water fetcher] usually bring to collect water?	Number of containers: ___ ___
Do you wash/clean your container(s) before collecting water? If 'no' probe: why not? If 'yes' probe: how often do you clean the container(s)? and do you use soap to clean your container(s) before collection water?	Yes ....1 No ....2 Not necessary (clean) ....1 Don't know how to clean ....2 Soap taste bad ....3 Don't have water, soap ....4 Other *(specify)* __________________96 Each time ....1 Often (at least once per week) ...2 Sometimes ....3 Never ....4 Yes ....1 No 2
5.2. Collection	
Do you rinse your container(s) before filling it/them with water?	Yes ....1 No 2
Do you use a funnel, utensil or other container to fill your container(s)?	Yes - funnel ....1 Yes - utensil ....2 Yes - container ....3 No - directly from tap 4
What is, **approximately**, the quantity of water collected each time someone goes to the source? *(Record in litres)*	Litres: ___________

What is, **approximately**, the total quantity of water collected each day? *(Record in litres)*	Litres: ___________
Do you consider this is enough to meet household needs?	Yes ....1 No 2
Which personal or domestic purpose required the greatest quantity of water ?	Drinking (household members) .....1 Cooking ....2 Handwashing ....3 Bathing/Showers ....4 Cleaning the house ....5 Washing clothes ....6 Feeding animals ....7 Other *(specify)* _________________96 Don't know 98
In the last week, has there been any time when your household did not have sufficient quantities of water, including for hygiene and cleaning?	Yes, at least once ....1 No, always sufficient ....2 Don't know 98
When quantities of water are not sufficient, which personal or domestic purpose is the most important for you? Drinking, cooking, handwashing, bathing or feeding animals.	Drinking (household members) .....1 Cooking ....2 Handwashing ....3 Bathing/Showers ....4 Cleaning the house ....5 Washing clothes ....6 Feeding animals ....7 Other *(specify)* _________________96 Don't know 98
Would you collect more water if a new source was located closer to your household?	Yes ....1 No ....2 Don't know 98
Would you be keen to walk further to collect a greatest quality of water?	Yes ....1 No ....2 Don't know 98

5.3 Post collection	
Once you come back from collecting water, do you use another storage facility? *If 'no' probe:* *Why not*	Yes (Use storage) ....1 No (same container) ....2 Storage are not necessary ....1 Containers are expensive ....2 Don't know what to use ....3 No room for storage ....4 Other *(specify)* _________________96
Which type of storage do you use to store the water?	Jerrycan ....1 Covered bucket ....2 Uncovered bucket ....2 Pot without handles ....3 Metal container ....4 Other *(specify)* ....96 Don't know 98
Where is/are the storage container(s) located? *If 'outside', probe:* *covered or uncovered?*	Inside the house ....1 Covered area outside the house ...2 Uncovered area outside the house .3
Do you use covered storage container(s) to store the water?	Yes ....1 No 2
Do you use a funnel or utensil to fill/refill your storage container? *If 'yes'* Do you wash/clean the tool used to fill/refill the container?	Yes, funnel ....1 Yes, utensil ....2 No ....3 Yes ....1 No 2
Do you refill the storage container if there is already water inside?	Yes ....1 No 2
Would you use the storage container if cracked or leaking?	Yes ....1 No 2

Do you wash the storage container when empty?	Every time ....1 Often ....2 Sometimes ....3 Never 4
If 'yes' Do you use soap to wash the inside of the container?	Yes ....1 No 2
Do you use the container to store: any other liquid (aside from water)?	Yes ....1 No 2
anything else than water?	Yes ....1 No 2
Do you [or any other member of your household] soak hands inside the storage container? (e.g. to fill cup)	Yes ....1 No ....
For what purposes do you use stored water? [Multiple answers possible]	Drinking ....1 Cooking ....2 Handwashing ....3 Bathing ....4 Feeding animals ....5 Let it stand and settle ....6 Cleaning the house 7
5.4 Water treatment	
Do you or any other member of this household do anything to the water to make it safer to drink?	Yes ....1 No ....2 Don't know 98

What do you usually do to make the water safer to drink?	Boil ....1 Add bleach / chlorine ....2 Strain it through a cloth ....3 Use water filter ....4 Solar disinfection ....5 Let it stand and settle ....6 Other (*specify*) _________________96 Don't know 98
Why don't you do anything to make the water safer to drink?	Water is already clean/safe ......1 It is too complicated ....2 It is not important ....3 It is too expensive ....4 It takes too long ....5 Don't know how ....6 Other (*specify*) _________________96
5.5 Consumption & Use	
What type of cup do you MOSTLY use for drinking water?	Plastic cup ....1 Metal/stainless cup ....2 Glass ....3 Bottle ....4 Don't know 98
Where do you store the cup(s) when not being used? *If 'outside', probe:* *covered or uncovered?*	Inside the house ....1 Covered area outside the house ...2 Uncovered area outside the house .3
Do you [or any member of your household] leave the cup on the ground when not being used?	Yes ....1 No 2

In general, do you wash/clean your cup before/after use? *if 'yes' probe:* *Do you ever use soap to wash/clean your cup?*	Yes, before use ....1 Yes, after use ....2 Yes, both ....3 No ....4 Yes ....1 No 2
Is there a tap on the storage container available for use?	Yes ....1 No 2
How do you generally fill the cup(s) with the stored water? Do you wash or clean the funnel or utensil to fill your cup?	Utensil used to fill the cup .....1 Cup soaked ....2 Water poured in the cup ....3 Tap used to fill the cup ....4 Yes ....1 No 2

Record end time: ______:______

[This form was adapted from Multiple Indicator Cluster Survey (MICS) Household Questionnaire]
Author: Cassivi Alexandra
Last update: 21/04/2020

Annexe F. Observations and Sanitary Survey

GENERAL INFORMATION	
Interviewer's name and number : ________________________ ID______	Date (dd/mm/year) : ______/______/____________
Study site : ☐ Site 1 – Peri-urban - Blantyre (Ndirande) ☐ Site 2 – Peri-urban - Blantyre (Mbayani) ☐ Site 3 – Rural - Chikwawa	Household number (HHID) : _____ _____ _____ _____ Respondent name : ______________________________
Record start time (hour : minutes) ________ : ________	
Household location (coordinates) _______________ | _______________	

WATER COLLECTION		
Stage I. Pre-collection *Location. Household*		
When not in use, is/are the collection container(s) kept in a place where it may become contaminated?	Yes (risk) ☐	No ☐
Number of containers used to collect water	Number of containers: _________	
What is(are) the type(s) of container(s)? *Record all items*	Jerrycan .... 1 Bucket .... 2 Pot .... 3 Metal bucket .... 4 Bottles .... 5 Rolling container .... 6 Bassin .... 7 Other *(specify)* ________________ 96	

Record approximate volume of the container(s) litres *Record all items*	Volume: C1______________ C2______________ C3______________ C4______________ C5______________	
Does the collection container have a large opening that is uncovered? *A large opening that is uncovered may increase the likelihood of contamination by providing a route for contaminants to enter the collection container.*	Yes (risk) ☐	No ☐
Is the collection container cracked or leaking? *A damaged or unclean collection container may increase the likelihood of contamination during collection.*	Yes (risk) ☐	No ☐
Does the inside of the container contain any visible signs of contamination (e.g. animal waste, sediment accumulation)? *Contamination in the container may constitute a risk to water quality*	Yes (risk) ☐	No ☐
Is the collection container used to store any other liquids? *Storage of liquids other than drinking water in the collection container, including water of lesser quality, may increase the likelihood of cross-contamination.*	Yes (risk) ☐	No ☐
Is the container used for any other purposes than collecting water?	Yes (risk) ☐	No ☐
Is/are the container(s) being washed before collecting water?	Yes ☐	No ☐
Ask the respondent to bring the container(s) to collect water to the water source		
Take a photo of all the container(s) used by the respondent to collect water		
Record time leaving the household (to go to the source): ______:______		

Stage II. Collection

Location. Water source

Record time arriving at the water source: ______:______

Water source location (coordinates) _______________ | _______________

What is the type of water source?	
	PIPED WATER
	Piped to yard / plot 12
	Piped to neighbour 13
	Public tap / standpipe 14
	Tube well / borehole 21
	DUG WELL
	Protected well 31
	Unprotected well 32
	SPRING
	Protected spring 41
	Unprotected spring 42
	Rainwater 51
	Tanker-truck 61
	Cart with small tank 71
	Water kiosk 72
	Surface water 72

Is the container used for any other purposes than collecting water?	Yes (risk) ☐	No ☐
Is/are the container(s) being washed before collecting water?	Yes ☐	No ☐
Take a photo of the water source		📷
Is there water available from this source? Is the source functional?	Yes ☐	No ☐

Take a sample of water at the water source (S1) *Label S1-HHID, Date, Time, Initials*	Record time : ______:______

Observe the respondent filling collection container

Is/are the container being rinsed before being filled?	Yes ☐	No ☐
Is a funnel, utensil or container used to fill the container(s)?	Yes ☐	No ☐
Take a photo of the tool (e.g., funnel, utensil) used to fill the collection container		
Take a sample of water in the largest (volume) collection container (immediately after being filled) with water(S2) *Label S2-HHID, Date, Time, Initials*		Record time : ______:______
Record time leaving the water source (to return to the household): ______:______		
Take a photo of the respondent carrying water		

Stage III. Post-Collection *Location: Household*		
Record time arriving at household: ______:______		
Is the water stored in a storage container or left in the same water container(s)?	Different container(s) ☐	Same container(s) ☐
Where is/are the container(s) stored?	Inside ☐	Outside : Covered area ☐ Uncovered area ☐
Is/are the container(s) stored in a place where it may become contaminated (e.g. on the ground)? *Improper storage of the final storage container (e.g. on the ground where animals and children may easily access it) may increase the likelihood of contamination, especially when household sanitation practices are poor.*	Yes (risk) ☐	No ☐
Is the final storage container cracked, leaking or unclean? *A damaged or unclean final storage container may provide an entry route for contaminants during storage.*	Yes (risk) ☐	No ☐

Does the inside of the storage tank contain any visible signs of contamination (e.g. animal waste, sediment accumulation)?	Yes (risk) ☐	No ☐
Is the final storage container used to store any other liquids? *Storage of liquids other than drinking water in the final storage container, including water of lesser quality, may increase the likelihood of cross-contamination.*	Yes (risk) ☐	No ☐
When not being filled, is the final storage container inadequately covered to prevent contamination? *A missing or inadequate cover may increase the likelihood of contamination by providing a route for contaminants to enter the final storage container.*	Yes (risk) ☐	No ☐
Is the final storage container used to store anything else than water?	Yes (risk) ☐	No ☐
Is the storage container refilled although not empty?	Yes (risk) ☐	No ☐
Is a funnel, utensil or container used to fill the storage container?	Yes (risk) ☐	No ☐
When not used is the tool (e.g. funnel, utensil or container) stored in a place where it may become contaminated (e.g. on the ground)? *Locating close to sources of contamination (e.g. directly on the ground, underneath vegetation, or in close proximity to sanitation facilities) may increase the likelihood of contamination.*	Yes (risk) ☐	No ☐
Is there a tap on the final storage container?	Yes ☐	No ☐
Take a photo of the tool used to fill the storage container		
Is the water from the final storage container directly used for other purposes (e.g. washing or bathing)? *Drinking water may be contaminated during collection for washing or bathing (e.g. by dirty hands or soiled garments). Spilt*	Yes (risk) ☐	No ☐

bathing-water may collect in the area and provide a source of contamination.		
Take a photo of the storage container(s)		
Take a sample of water in the largest (volume) collection container after being stored (S3) *Label S2-HHID, Date, Time, Initials*		Record time : ______:______
Is there anything done to the water to make it safer to drink?	Yes ☐	No ☐
If yes: what is done to make the water safer to drink?	Boil .... 1 Add bleach / chlorine .... 2 Strain it through a cloth .... 3 Use water filter .... 4 Solar disinfection .... 5 Let it stand and settle 6	
If household-level treatment is practiced, is there evidence that it is being carried out ineffectively? *If household treatment is being carried out ineffectively (e.g. inadequate chlorine concentration or contact time, only heating water as opposed to boiling, cracked/dirty filter [e.g. ceramic candle], expired treatment chemicals [e.g. chlorine, aluminum-based coagulants]), contaminants may not be adequately removed/ inactivated.*	Yes ☐	No ☐

Stage IV. Consumption & Use *Location: Household*		
Ask the respondent to provide a cup of water that members of this would drink		
Where is/are the cup being stored?	Inside ☐	Outside : Covered area ☐ Uncovered area ☐
Is/are the cup stored in a place where it may become contaminated (e.g. on the ground)? *Improper storage of the final storage container (e.g. on the ground where animals and children may easily access it) may*	Yes (risk) ☐	No ☐

increase the likelihood of contamination, especially when household sanitation practices are poor.		
Is the cup being wash/clean/rise before being filled?	Yes W/ soap ☐ W/O soap ☐	No ☐
From where is the cup of water being filled?	Collection containers .... 1 Storage container .... 2 Tap .... 3 Bottle of water .... 4 Other (*specify*)_________________96	
How is the cup being filled with water?	Utensil used to fill the cup .... 1 Cup soaked .... 2 Water poured in the cup .... 3 Tap used to fill the cup 4	
Is the tap or utensil used to draw/collect water from the final storage container inappropriate or unclean?	Yes (risk) ☐	No ☐
What type of cup is provided by the respondent?	Plastic cup .... 1 Metal/stainless cup .... 2 Glass .... 3 Bottle 4	
Does the inside of the cup contain any visible signs of contamination (e.g. animal waste, sediment accumulation)?	Yes (risk) ☐	No ☐
Take a photo of the storage container(s)		
Take a sample of water in the cup (S4) *Label S2-HHID, Date, Time, Initials*		Record time : ______:______

[This form was designed based on WHO sanitary surveys]

Author: Cassivi Alexandra
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