Review Paper

Reliability of water supplies in low and middle-income countries: a structured review of definitions and assessment criteria

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ABSTRACT

The unreliability of water supplies in developing countries is a widely recognised concern. However, unreliability means different things in the variety of literature on water supplies, and no unified definition or assessment criteria exists. We review definitions of water supply reliability used in existing literature, as well as the various ways in which it is assessed. Thirty-three papers were selected for review that reported on reliability of domestic water supply and were based on empirical research in developing countries. Explicit definitions of reliability are given in four out of the 33 papers reviewed. These definitions vary, but features common are the functionality of the water supply system itself, and the extent to which it meets the needs of water users. Assessment criteria also vary greatly, with the most common criterion in urban settings being the duration/continuity of supply in hours per day, while in rural settings, the proportion of functional water systems is commonly used. The heterogeneity in the definitions and assessment criteria found in the review is perhaps indicative of a multi-attribute nature of the concept of reliability and any unifying definition and assessment criteria might do well to take this into account.

Key words | assessment criteria, definition, reliability, review, water supply

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INTRODUCTION

In 2012, an estimated 89% of the global population had access to safe water, and the Millennium Development Goal (MDG) target of halving the proportion of the world's population by 2015 had seemingly been met (UNICEF/WHO 2012). However, caution had already been noted that the indicator used to track progress against this target – 'use of an improved source' – did not sufficiently address some key aspects of water safety and access. A review estimated that 1.9 billion people use either an unimproved source, or an improved source with faecal contamination (Bain *et al.* 2014). Further – and of main interest in this review – is the note in the MDG update that reliability of water supply was not addressed in the existing indicator (UNICEF/WHO 2012).

Estimates vary, but around 300 million people globally are thought to be served by piped water supplies that are intermittent, with supplies available for less than half the day (Kumpel & Nelson 2016). Across rural sub-Saharan Africa, a third of hand-pumps are thought to be non-functional at any given time (Rural Water Supply Network 2009).

Intermittent or unreliable water supplies and episodes of low pressure have been associated with increased risk of gastrointestinal illness (Hunter *et al.* 2005; Nygård *et al.* 2007; Majuru *et al.* 2011; Lechtenfeld 2012). This may occur through, among other things, intrusion of contaminants as a result of back-siphonage during pressure losses, or households using unsafe alternative water sources during supply interruptions. In addition, unreliable water supplies may

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also impact negatively on income, productivity and educational attainment (Kudat *et al.* 1993; Subbaraman *et al.* 2012) as households – particularly women and children – often have to engage in labour- and time-intensive coping strategies (Majuru *et al.* 2016).

Unfortunately, robust literature on the scope of the problem of water supply reliability remains lacking. No unified definition or measurement approach for water supply reliability exists (UNICEF/WHO 2012), and the data that are available are often sketchy (Kleemeier 2010). Much of the often-cited data on the reliability of water supplies for piped systems are from the World Bank's International Benchmarking Network for Water and Sanitation Utilities (IBNET 2011). The database contains information on duration of supply in hours per day and/or proportion of residential customers receiving intermittent supply from utilities in 85 countries. Because the data are reported by the utilities themselves, the quality depends greatly on the accuracy of this reporting (UNICEF/WHO 2011).

Systematically collected data on the reliability of water supplies for non-piped systems – typically in rural or peri-urban communities – are even more limited. The most often cited figures are from the Rural Water Supply Network (2009), which are themselves a compilation from various sources and report only on functionality of handpumps in sub-Saharan Africa. Thus, the little systematic data that are available are often limited to specific communities, regions or water supply technologies, and are sometimes not nationally representative.

The Sustainable Development Goals (SGDs) have now superseded the MDGs, and SDG 6 seeks to ensure access to safe water and sanitation for all. The indicator for monitoring Target 6.1 on drinking-water is: 'the proportion of the population using safely managed drinking water services'. The 'safely managed' indicator comprises three criteria: the source should be located on premises; water available when needed; and free from faecal and chemical contamination (World Health Organization/United Nations Children's Fund (WHO/UNICEF) 2015). While water supply reliability is captured under the availability criterion, the lack of harmonised definitions and assessment approach has made aggregation of data across countries and over time difficult (World Health Organization 2017).

The aim of this paper is to provide a review of the various definitions and assessment criteria of water supply reliability that have been used in the literature. It is hoped that this summary will contribute to the identification of clearer definitions and assessment criteria that can be used to evaluate the reliability of water supplies, particularly in developing countries.

METHODS

Before describing the methods, we outline a conceptual overview of reliability of water supplies.

A conceptual overview of water supply reliability

As Galaitsi *et al.* (2016) note, the lack of a harmonised definition or assessment approach for water supply reliability is perhaps reflective of the multi-faceted nature of the problem, as reliability can be conceived in various ways. In their early studies on unreliability of water supplies and its impact on households, Kudat *et al.* (1993) proposed that as a commodity, water comprises three main attributes: quantity, quality and pressure. Where these three attributes are not at their optimum level, the water supply is said to be unreliable. Similarly, a proposed definition of reliability from Moriarty *et al.* (2011) is where the water supply meets quantity, quality and accessibility needs at a given time, and is available within a known schedule ('punctuality of service'), even if is not continuous/24 hour supply. Moriarty *et al.*'s proposed definition goes on to note that 'problematic services are characterised by down time, significant breakdowns, and slow repairs'.

Taken together, these definitions suggest that while it could be argued that attributes such as quantity and quality should be considered separately from reliability (Zérah 1998; World Health Organization 2017), these attributes are interlinked; and reliability can be defined/assessed on a scale, and is not necessarily a binary concept.

For the purposes of this review, we broadly consider reliability as a feature of water supply comprising several interlinked attributes, including: continuity, e.g., available 24 hours a day every day, or for part of the day on some days; predictability, e.g., supply not continuous, but

Table 1 | Databases and search engines used

Academic	Search engines	NGO/Donor agencies
Web of Knowledge	Google Scholar	AfDB, ADB, IDB
Scirus (Elsevier)	Google Web	DFID
MEDLINE Ovid		USAID
PubMed		World Bank
ProQuest Dissertations and theses		Water Aid
CINHAL EBSCOHost		WHO

available at regular intervals; functionality, e.g., breakdown in the system; and pressure, where fluctuations may result in limited or no supply.

Literature search methods and selection criteria

Scoping searches can be described as brief searches aimed at mapping the existing literature, and can be useful in refining research questions, potential resources required, clarification of terms related to the research question, etc. (Armstrong *et al.* 2011). We conducted a scoping search prior to the actual search for the review to identify the various terminology used in relation to reliability in the water supply literature. Literature searches for grey and published literature were then conducted in a number of databases and websites shown in Table 1.

The search terms used in the academic databases were: 'water supply' OR 'safe water' OR 'drinking water' OR 'domestic water' OR 'household water' OR 'water point' AND reliab* OR sustainab* OR availab* OR function* OR regular OR access OR intermitten* OR interrupt* OR constant OR continu* OR consistent OR 'operation and maintenance' OR breakdown.

Where possible, searches were specified as title, abstract and keyword searches. It was not possible to apply the exact search string among all the resources searched. In Google and Google Scholar, three searches were conducted to cover the search string detailed above. Each of these searches contained the terms relating to water (water supply, etc.) and five of the terms relating to reliability, until all the terms had been covered. Among the websites of non-governmental organisations and donor agencies where the number of search terms was similarly limited, only the terms relating to water were applied.

Papers retrieved from the search were screened independently by two reviewers for relevance according to the following criteria:

- Report on reliability of domestic water supply
- Based on primary data from developing countries
- Report on operational reliability of water supply, not water scarcity, e.g., due to drought
- Provide a definition and/or assessment criteria of reliability.

The full texts of papers in English whose abstracts met the criteria were retrieved and reviewed in detail. From Google and Google Scholar, the first 50 hits from each of the searches were checked for potentially relevant papers. The reference lists of these included papers were also checked for potentially relevant literature. Data from major national surveys of the Asian Development Bank (ADB) and Pan American Health Organization (PAHO) were also reviewed. We defined developing (low and middle income) countries as per the World Bank classification.

RESULTS

Seventy-eight documents were reviewed for this assessment and 33 were found to be relevant. Among those excluded, reasons included lack of clarity on both how reliability was defined and consequently assessed and results being presented as an overall index of sustainability, from which data on reliability specifically could not be drawn. Two of the papers (Zérah 1998, 2000) were based on the same survey and were regarded as one paper for the purposes of the review.

Of the 33 papers reviewed, half were carried out in sub-Saharan Africa (Tables 2–4). The data from PAHO covered 19 countries in Latin America and the Caribbean region, while that from ADB covered 40 utilities in Lao, Malaysia and Vietnam. Fifteen of the studies evaluated reliability in rural settings, 13 in urban and five in both rural and urban settings. The ADB survey data from south-east Asia was

Table 2 | Literature on urban settings

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
Aderibigbe *et al.* (2008)	Determine the availability, adequacy and quality of water supply	Urban Nigeria: 750 female respondents randomly selected from 3 communities	Descriptive cross-sectional study, using structured questionnaires	None stated	62.9% of respondents house connection	15% had water more than 3 times a week; 30.1% had water 2 or 3 times a week; 54.9% had water occasionally or once a week
Andey & Kelkar (2009)	Evaluate influence of continuous and intermittent water on domestic water consumption	Urban India: 4 cities; Ghaziabad: 35 households out of 48; Jaipur: 195 households out of 206; Nagpur: 214 households out of 330; Panji: 51 households out of 120 households	Six measurements repeated times over 1 year for both modes of supply. Average consumption calculated from meter readings, duration of survey and number of people in households	None stated	Piped supply	Ghaziabad: 10 hours/day; Jaipur: 3 hours/day; Nagpur: 16 hours/day; Panji: 5 hours/day
Asian Development Bank (2007)	Help water utilities southeast Asia to assess their performance	Urban southeast Asia 2005: 40 water utilities; 17 from Vietnam, 17 from the Philippines, 5 from Malaysia and 1 from Lao PDR	Water utility questionnaire	None stated	Piped supply	24 hours a day on average for Malaysia and Lao; 23 hours a day on average for Vietnam and the Philippines
Ayoub & Malaeb (2006)	Investigate impact of intermittent supply on water quality	Urban Lebanon 2003–2004: 181 water samples	Quantitative. Samples collected from water network before storage in household tanks and after storage from household tanks	None stated	Piped supply	Once every 2 days

(*continued*)

Table 2 | continued

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
Baisa *et al.* (2010)	(i) Develop a model describing the optimal intertemporal depletion of each household's private water storage if it is uncertain when water will next arrive to replenish supplies; (ii) evaluate the potential welfare gains that would occur if alternative modes of water provision were implemented	Urban Mexico 2005 data	Model calibrated using data from the Mexican National Household Survey of Income and Expenditure survey	None stated	Piped supply	1 day per week: 2.8%; 2 days per week: 2.1%; 3 days per week: 3.8%; 4 days per week: 0.2%; 5 days per week: 1.3%; 6 days per week: 0.2%; Daily at limited hours: 21.6%; Daily at all hours: 68.0%
Caprara *et al.* (2009)	Investigate the relationship between the socio-economic characteristics and community practices that take place indoors (e.g., garbage disposal, water storage practices) affecting *Ae. aegypti*	Urban Brazil 2005	Mixed methods. Purposive sampling of 6 blocks in city of Fortaleza 204 households total: 51 middle class households, 153 under-privileged households	None stated	Piped supply	*Middle class:* 2–5 dys/wk: 0; 6–7 dys/wk: 39 (100%); 3–12 hrs/dy: 23 (59%); 13–24 hrs/dy: 16 (41%). *Under-privileged class:* 2–5 dys/wk: 30 (21.4%); 6–7 dys/wk: 110 (78.6%); 3–12 hrs/dy: 37 (26.4%); 13–24 hrs/dy: 103 (73.6%)
Gulyani *et al.* (2005)	Examine current water use and unit costs in three Kenyan cities and test the willingness of the unconnected to pay for piped water, yard connections, or an improved water kiosk (standpipe) service	Urban Kenya 2000: 674 households interviewed in 22 sites in the three urban areas	Cross-sectional survey using structured questionnaires	None stated	House connection; Yard tap; Kiosk	House connection: 36% <8 hrs/dy, 28% 8–16 hrs/dy, 36% >16 hrs/dy. Yard tap: 47% <8 hrs/dy, 32% 8–16 hrs/dy, 21% >16 hrs/day. Kiosks: 36% <8 hrs/dy, 54% 8–16 hrs/dy, 10% >16 hrs/dy

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Table 2 | continued

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
Howard (2002)	Develop a model of water supply surveillance for urban areas of developing countries that provides reliable assessment of water supplies, with particular emphasis on the urban poor	Urban Uganda 1997–2000: 1,652 water points in 10 locations	Multi-criteria zoning to identify vulnerable communities and structured observation of water points and structured questionnaires	Discontinuity was defined as being the physical absence of water flowing from the source	Piped water. Point sources: protected springs boreholes/ tubewells with handpumps, dug wells with handpump	309 (18.7%) water points had discontinuity. Piped: 245 (25.7%); Protected: 33 (6.7%); Unprotected: 31 (15.1%); Discontinuity occasional (70%) seasonal interruption relatively common and daily/monthly interruptions far less common
Mycoo (1996)	Provide a demand-oriented perspective on water provision for domestic users, examining cost recovery potential based on household willingness to pay more for an improved service and water pricing	Urban Trinidad: Stratified sampling of 6 settlements (total of 420, sampling rate 0.34%). Criteria: location, elevation and slope, income, housing and land tenure, level of service and the number of hours of water received	Cross-sectional survey using contingent ranking, contingent valuation and observed behaviour of the household in producing water	None stated	Piped: House connection; Yard tap; Communal tap	4S% of customers receive a 24 hour supply seven days a week
Pattanayak *et al.* (2005)	Evaluate how coping costs and willingness to pay vary across types of water users and income	Urban Nepal 2001: Clustered sampling (probability-to-size), 1500 households in five municipalities of Kathmandu Valley	Mixed methods cross-sectional survey using 17 purposive, open-ended discussions, 2 focus groups, and 150 pre-tests in designing the survey instrument	None stated	70% piped, 30%: private wells, public taps, stone spouts, and water vendors. About 1% of the connected households share a connection with other households	Water was available from private connections on average about 2 hours per day in the wet season and 1 hour per day in the dry season

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Table 2 | continued

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
Shah (2003)	Establish the value of water supply services to people of Zanzibar Town by measuring willingness to pay for reliable water services, to provide basis for change of the financing policy for water supply services management	Urban Zanzibar: 300 households out of 10 Shehias; (0.94% of the town's households). In some instances household had to be targeted to balance political affiliations	Cross-sectional survey using structured questionnaire	Availability of water at a point of consumption (household or public stand-pipe) for 24 hrs a day, 7 days a week, 365 days a year	Piped supply	20.7% had 'no problem' with supply; 27% had water for 1–5 hrs/dy; 24.3% for 5–10 hrs/dy; 13% 5–10 hrs/dy; 12.7% for 15–24 hrs/dy; 0.3% did not respond and 0.7% did not know
Thompson *et al.* (2000)	Assess changes in domestic water use	Urban Kenya, Tanzania, Uganda 1997: Unpiped households: 99; Piped households: 349	Cross-sectional follow up study, 30 years later, using semi-structured interviews, observation, interviews with key informants, field observation, review of secondary literature	None stated	Piped in house connection	Water available 24 hrs/dy: 56%, <12 hrs/dy: approximately 40%; 1–5 hrs/dy: approximately 20%
Virjee & Gaskin (2010)	Ascertain the willingness to pay for changes in the level of service experienced by users	Trinidad and Tobago 2003: The Central Statistical Office's Continuous Sample Survey of Population sampling method was used to randomly select 1,419 households, using a two-stage stratification scheme based on geography and labour force characteristics	Cross-sectional multi-part survey	None stated	WASA in-house piped connection only; WASA in-house connection + secondary source; No in-house connection	Water available 24 hrs/dy, 7 dys/week: 27%; Almost 30% received no water from WASA at all during the time of the survey. 68% had water storage tanks on their premises with an average installed capacity of 610 gallons. As a result of these coping mechanisms, 82% of those with tanks had a 24-hour water supply

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Table 2 | continued

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
Widiyati (2011)	Present evidence of willingness to pay to avoid costs associated with intermittent water supply from Bandung Municipality in Indonesia	Urban Indonesia 2011: 200 people interviewed in survey	Cross-sectional survey using structured questionnaires	None stated	Piped	24 hour supply: 60%. For about 40%: water is rationed from 1 hour every 2 days to about 18 hours per day. Mean hours of supply in actual study was 2.4 based on a numbered scale of 1: ≤3 hrs/day, 2:3–6 hrs/dy; 3: 7–10 hrs/dy; 4: 11–13 hrs/dy; 5: other
Zérah (1998, 2000)	*Study 1:* Measure the costs of unreliability *Study 2:* Understand the household demand for a service by assessing the actual behaviour adopted by households when they have to cope with an inadequate service	Urban India 1995: Two stratified samples of 678 households in four zones of urban Delhi	Cross-sectional survey using structured questionnaires	A service is reliable if it is provided in time, and with the quality and the quantity required	Piped	On average, 13 hrs/dy, about 40% have water around the clock, about 13% do not get water at all. High pressure: 8.5%; Average pressure: 49.1%; Low pressure: 32.9%; No pressure: 9.5%, >12 hrs: 50.3%; 6–12 hrs:8.6%; 2–6 hrs: 28.2%; ≤2 hrs: 12.8%
Zérah (2002)	Determine the level of service provided by the Vijayawada Municipal Corporation (VMC); assess the existing households' coping strategies; evaluate the cost of water supply and sanitation and measure the level of satisfaction of the inhabitants of Vijayawada	Urban India 2002: 167 households in 15 wards (out of 50 wards) and in neighbouring villages of Vijayawada	Cross-sectional survey using structured questionnaires	None stated	Piped connections, private boreholes, public taps	Municipal water connection: 3.83 hours of supply in summer, 3.73 in winter. Private boreholes: On average, households spend almost 2 hours to pump water. Public taps: water is available every day in winter in 93% of the cases and in 96% of the cases in summer. Otherwise, water is available on alternate days. In winter and in summer, supply is similar (around 6 hours)

Table 3 | Literature on rural settings

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
Admassu *et al.* (2003)	Assess utilisation, functionality, community participation and sustainability of water projects	Rural Ethiopia, 2001–2002: 11 randomly selected peasant associations, making a total of 768 households and 114 site observations	Descriptive cross-sectional study using structured questionnaires, observation and 4 focus group discussions	Functioning: proper physical state of water supply projects in relation to their present working condition at the time of the survey	Protected spring, hand-dug wells with pumps	52 out of 442 source points not functioning. (11.76%)
Arnold *et al.* (2013)	Assess existing water infrastructure, determine the reliability of water sources, assess the water quality available for domestic use, and evaluate community awareness as related to water, sanitation, and hygiene	Rural Ghana, 2008–2010: 8 villages selected on basis on participation in previous community development projects and request by villagers	Cross-sectional surveys in summers of 2008–2010 using sanitary surveys, conversations with villagers, 1 focus group, key informant interviews and water quality testing	None stated	Standpipes, boreholes, dug wells and shallow wells	One-third of standpipes not functioning at time of survey
Davis *et al.* (2008)	Explore the contribution of various types of post-construction support (PCS) to the sustainability of rural water supply systems in Bolivia	Rural Bolivia 2005: 99 communities	Cross-sectional mixed methods using household survey, system operator survey, focus group with village leaders, focus group with women, focus group with village water committee	None stated	94% had house connections or yard taps; 27% had public taps; 8% had wells	Breakdowns as reported by operators: mean 2, household members: mean 3, women's focus groups: mean 2.9. Typical duration of breakdowns (dys) operator: mean: 4.2, household members: 9.8, women's focus groups mean 15.8. Systems received prior to 2000, range between 5 and 8 years in age

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Table 3 | continued

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
Hoko & Hertle (2007)	Evaluate the sustainability of a rural water point rehabilitation project that was carried by a local NGO	Rural Zimbabwe: 144 water points; Mwenezi: 37; Gwanda: 41; Bulilima: 38; Mangwe: 28	Cross-sectional quantitative study using structured observation of water points and structured questionnaires	None stated	Boreholes with handpumps	Water points not working in Mwenezi: 4%; Gwanda: 17%; Bulilima: 13%; Mangwe: 25%. Operation of the water points deemed difficult by a minimum of 19% (Mwenezi) to a maximum of 64% (Mangwe) of respondents
Jiménez & Pérez-Foguet (2011)	Establish relationships between technology, functionality and durability of rural water points	Rural Tanzania 2005–2006: 5,921 water points 15 districts covering 15% of rural population	Quantitative cross-sectional survey (Water Aid data)	None stated	Handpumps 2,326 (39.3%); Motorised pumping systems 2,180 (36.8%); Gravity fed 1,263 (21.3%); Other (protected springs, rainwater-harvesting, windmill powered water point): 152 (2.6%)	[a]
Kleemeier (2000)	Explore the assumption about the link between participation and sustainability by presenting findings from a study of operation and maintenance on rural water supplies that were constructed under a programme widely praised for its exemplary approach to community participation	Rural Malawi 1997–1998: Sample includes schemes from all three of Malawi's administrative regions. Sample limited to schemes that originally had less than 120 km of pipeline. 17 schemes visited for 1 day and a follow-up visit to four of the schemes	Cross-sectional survey involving discussion with water schemes' monitoring assistant, main committee, tap committees, repair teams and observation of schemes	None stated	Piped-communal taps	Overall, 66% of the taps supplied water a minimum of 50% of the days in the previous 3 months. In 4 of the smallest schemes (13–37 taps), 80% or more of the taps supply water on a regular, if not continuous basis

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Table 3 | continued

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
Majuru *et al.* (2012)	Assess the impact of unreliability on water service indicators of distance to source, water quantity and quality	Rural South Africa 2007–2008: 3 communities of which one was a control/reference community, 114 households in total	Quasi-experimental with repeated cross-sectional surveys of water supplies and daily symptom diaries over 56 weeks	None stated	Piped-communal taps; Drilled wells with handpumps; Water tanks	Handpumps: broke down for about 2 weeks every 3 months; 83%; Tanks: water ran out after 2 weeks: 50% Communal taps Community 1: 2 breakdowns 89%, Community 2: 4 breakdowns: 58%
Moon (2006)	Assess the role of private sector participation in developing and sustaining rural water schemes	Rural Tanzania 2004–2006: 6,812 distribution points in 3 regions and 1 district in another region	Quantitative cross-sectional survey (Water Aid data)	None stated	Four commonly used extraction systems in the study area: pump and engine, Afridev handpumps, Tanira handpumps, and gravity systems	Pump and engine schemes have a functionality rate of 48% and the others vary between 60% and 70%
Musonda (2004)	Identify factors that contribute to the promotion of sustainability of rural water supplies in Zambia	Rural Zambia 2001: 16 water points in Mazabuka District	Mixed methods cross-sectional survey with structured questionnaires and observations	None stated	Hand-dug well and boreholes with handpumps	8 functioning out of 16, 3 in disrepair for 2 months, 1 in disrepair for 4 years, 1 very difficult to operate, 3 functioning but had problems. Five years was the average age for functional handpumps, as they had been constructed between 1995 and 2000. All semi-functional handpumps had been constructed between 1980 and 1996

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Table 3 | continued

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
Norwegian Agency for Development Cooperation (2008)	Carry out a descriptive based analysis of Norad's previous support to the WSS sectors in partner countries, with emphasis on Kenya and Tanzania during the period 1975–1995	Rural Kenya and Tanzania	Archive search and literature study, single and group interviews cross-sectional field work	None stated	Kenya: piped water supply. Tanzania: handpumps, gravity schemes	*Rukwa:* between 65% and 74% of 2,000 water points still operating and in daily use. *Kigoma:* between 76% and 78% of 800 water points still working and in daily use. *Kenya:* 16 towns, 91% of water points still working and in daily use
Schweitzer (2009)	Evaluate the efficacy of community management in sustainability of rural water supply	Rural Dominican Republic 2008–2009: Stratified random sample of 64 water systems built in the DR by initiatives of the National Institute of Potable Water (INAPA, 23) and Peace Corps (41) out of a total cohort of 185 (118 PC and 67 INAPA)	Mixed methods using secondary data analysis observation (participant and non-participant) focus group/key informant interviews household surveys formal versus informal interviews	None stated	INAPA (21): Public or shared taps: 1%; Patio connections: 77%; Household connections: 9%; Multiple connections: 14%; Peace Corps (40): Public or shared taps 6%: Patio connections 68%; Household connections 8%; Multiple connections 18%	Systems with major repairs within last month: INAPA: 80%, Peace Corps 45%. Days per week with water INAPA: 5.7, Peace Corps: 6.2. Hours per day with water INAPA: 11.4, Peace Corps: 16.6. Average system age (years) INAPA: 5; Peace Corps: 6.85

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Table 3 | continued

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/synonym	Type of supply	Estimates of (un)reliability
World Bank–Netherlands Water Partnership (2009)	Investigate how the provision of support to communities after the construction of a rural water supply project affected project performance in the medium term	Rural Peru and Ghana. Peru mid 2004, Ghana late 2004. Peru: 99 villages, 25 households in each village, 1,360 male and 1,089 female respondents	Cross-sectional mixed methods using household survey, system operator survey, focus group with village leaders, focus group with women, focus group with village water committee	None stated	Handpumps, public taps and house connections	[b]

[a]Functionality: handpumps: 45.31%, gravity-fed systems: 48.61%, motorised pumps 44.36%, other systems: 36.18%. Aggregated functionality: 45.4%.
Handpump functionality dropped from 61% in first 5 yrs to 6% in the 25 yr period. Motorised systems started at 77% and dropped to 13%, gravity-fed systems 66% to 20%. Aggregated rate: 35–47% working 15 yrs after installation. >30% of WP become non-functional after the first 5 yrs and after this the functionality rate decreases at a slower rate (another 30% become non-functional in the following 15 yrs). Handpumps show least favourable functionality rate; gravity-fed show irregular trend between periods but best performance in the long-run; motorised pumping systems have a very good performance in the first period and maintain a similar descending slope as others in the long term.

[b]Peru: Taps working (operator data): FONCODES Average: 95%; SANBASUR Average 93%; Average hours of operation/day (household data): FONCODES: 18.8; SANBASUR: 19.9. Average major unplanned interruptions in water supply service for at least 1 day in past 6 months (operator data): FONCODES: 89%; SANBASUR: 59%; (Leaders): FONCODES: 70%; SANBASUR: 55%. Average system age: FONCODES: 7.57 years; SANBASUR: 6.13 years. Average number of days to fix major problem operator: FONCODES: 4.53; SANBASUR: 1.06; leaders: FONCODES: 2.08; SANBASUR: 2.58. Ghana: % of villages where all project handpumps are working (89): Brong Ahafo: 88; Volta: 92. % villages with working systems that had a breakdown in last 6 months (57): Brong Ahafo: 58; Volta: 55. Average years since completion: Brong Ahafo: 6.2; Volta: 5.8 (Average 6). Median days to repair the system last time it broke (reported by hhs) (20): Brong Ahafo: 18; Volta: 22.

Table 4 | Literature on both urban and rural settings

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/ synonym	Type of supply	Estimates of (un)reliability
Akosa (1990)	Develop of a Data Envelopment Analysis method to combine assessment of technical, financial, economic, institutional, social and environmental aspects of water supply and sanitation projects	Rural and urban Ghana, 1986–1988: 6 water supply projects over a 30-month period	Cross sectional surveys with observation, records from treatment plants, interviews with plant operators	None stated	Piped drilled wells with handpumps; Hand-dug wells with handpumps	*
Asian Development Bank (2009)	Assess project performance and identify lessons for maximising the development effectiveness of water supply and sanitation interventions, by conducting rigorous impact evaluation	Rural and urban Punjab, Pakistan: 7 randomly selected districts of the 30 covered by the Punjab Rural Water Supply & Sanitation Project (PCWSSP) and the Punjab Community Water Supply & Sanitation Project (PCWSS). 115 subprojects were identified using stratified random sampling, a total of 1,301 treatment households covered by a project and 1,301 comparison households outside the projects	Mixed methods using key informant interviews, focus group discussions, and household surveys. Comparison communities identified using district census reports. Community-level parameters used for matching: (i) total village area; (ii) number of households with potable water; (iii) average household size; (iv) literacy rates	None stated	92% of the project communities had a community water supply system, while 8% of comparison communities did. 24% depended on hand pumps in project areas and 54% in the comparison communities. 40% served by tube wells in project communities and 24% in comparison communities	89% PCWSSP functional, and 68% of PRWSSP. Households receiving water received on average 5 hours of supply per day. 18% of households in project areas used suction machines to deal with low pressure. Down time less than 3 days for 2/3 of major repairs
Bourgois *et al.* (2013)	Survey of the quantity and quality of existing water access points in three districts in Sierra Leone	Rural and Urban Sierra Leone: 2,859 drinking water access systems in 3 districts	Survey of water points and interviewers with local leaders of villages	None stated	Spring box: 2; bore hole: 499; hand-dug well: 2,028; open well: 330	30% of the finished, complete borehole systems were non-functional due to a broken pump

(*continued*)

Table 4 | continued

Author(s), year	Objective(s)	Setting, year and sample	Methods	Definition of reliability/ synonym	Type of supply	Estimates of (un)reliability
O'Hara *et al.* (2008)	Quantify current level of access to safe water and sanitation in rural and urban communities across the Republic of Kazakhstan	Rural and urban Kazakhstan 2005: 7,515 people (0.05% of the population)	Cross-sectional in-depth questionnaire survey administered to 7,515 people; 250 semi-structured interviews with individuals from urban and rural settlements, as well as officials working in various organisations concerned with water supply and health issues; and 16 focus group discussions with a range of stakeholder groups	None stated	Piped	Urban dwellers report service cuts on 6 days a month for 8–10 hours per day. Rural dwellers report cuts of 15–16 hours on an average of 21 days a month. People living in upper floors of high-rise buildings have cut-offs due to low pressure
Pan American Health Organization (2001)	Monitor and evaluate the situation of drinking water and sanitation in the region of the Americas	Rural and urban parts of the Americas**	Questionnaires collation of information already existing in the countries, through consultations of documents and reports of entities of the sector and government institutions, results of household surveys, applied research and sectoral analysis or other pertinent studies conducted in the sector	None stated	Piped and unpiped	Urban systems provided with water intermittently: 0–100%. Urban population provided with water intermittently: 0–99.9%. Rural systems in operation: 6–100%

*Accra-Tema Water Supply: Power outages involved 193 faults lasting a total of 707 hrs 7 min in 3 years (1986–88). Frequency of fault: 1 fault in 5.67 days. Duration: average 3.67 hrs/fault. Plant down time: 2.7%.
Borehole water supply: 21.7% down time.
Package plant water supply: 20.3% down time. % of time when plant was operating with inadequate supply of chemicals (including periods of chemical rationing) 58.7%.
2,500 Drilled wells water supply: Target established is 90% of pump operational at all times. Achievement is 85% of all handpumps operational. Down time is 15%.
3,000 Drilled well water supply: Target established is 90% of pumps operating at all times. Achievement is 40% of all hand pumps operational. Down time is 60%.
Hand dug well: Pump down time is calculated as 2.3% but water is available through the hatch.
**Countries covered in the survey were: Anguilla, Antigua & Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadalupe, Guatemala, Guyana, Haiti, Honduras, Montserrat, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts & Nevis, Saint Lucia, Suriname, Trinidad & Tobago, Turks & Caicos Islands, Uruguay, Venezuela and Virgin Islands.

for utilities in urban areas, whereas that of PAHO covered both urban and rural areas.

Definitions of reliability

Definitions or descriptions of reliability are explicitly stated in four papers. A list of these papers and others in the review is given in Tables 2–4. These definitions vary considerably, including: 'the physical absence of water flowing from the tap' (Howard 2002); 'availability of water at a point of consumption (household or public stand-pipe) for 24 hours a day, 7 days a week, 365 days a year' (Shah 2003) and 'a service is reliable if it is provided in time, and with the quality and quantity required' (Zérah 2000).

Although none of the definitions is shared by more than one paper, there is some degree of commonality in the features used by the different studies as part of their definition. One is to define reliability in terms of the water supply system itself and the extent to which it works (Howard 2002; Admassu *et al.* 2003). The other defines reliability in relation to the extent to which the needs of water users are met (Zérah 1998, 2000).

Assessment of reliability

The criteria used to assess reliability also differ somewhat. For example, Akosa (1990) quantifies reliability as the 'fraction of the time when the service is available to the user', while Kleemeier (2000) reports on the 'proportion of taps supplying water at time of survey and preceding 3 months'. Some assessment criteria are shared by more than one paper and seem to be specific to the setting, i.e., rural or urban.

The assessment criteria used in urban settings are presented in Table 5. The most common criterion used to assess reliability of water supplies in urban settings/piped systems is duration of supply in hours per day. This criterion is used in 12 of the 18 studies reporting on urban settings (Zérah 1998, 2000, 2002; Thompson *et al.* 2000; Pan American Health Organization 2001; Shah 2003; Gulyani *et al.* 2005; Pattanayak *et al.* 2005; Asian Development Bank 2007; Andey & Kelkar 2009; Caprara *et al.* 2009; Baisa *et al.* 2010; Virjee & Gaskin 2010; Widiyati 2011; Jiménez & Pérez-Foguet 2011).

Among the literature covering rural settings, seven papers (Pan American Health Organization 2001; Admassu *et al.* 2003; Davis *et al.* 2008; Asian Development Bank 2009; World Bank–Netherlands Water Partnership 2009; Jiménez & Pérez-Foguet 2011; Arnold *et al.* 2013) report on the proportion of water sources functional at the time of the survey (Table 6). Downtime (duration of breakdowns in the water supply system) is reported in five of the papers (Davis *et al.* 2008; Asian Development Bank 2009; World Bank–Netherlands Water Partnership 2009; Majuru *et al.* 2012; Arnold *et al.* 2013).

Three of the papers report on ease of operation of handpumps. In a study in Zimbabwe, Hoko & Hertle (2006) report that users had difficulty in operating handpumps, and in some instances up to 100 strokes were required before water was discharged. Similarly, Musonda (2004) finds that women and children, in particular, sometimes had difficulty in collecting water from handpumps because they were too stiff to operate.

Lifespan of water supply systems

Five papers assess reliability in relation to the age of water supply systems. Kleemeier (2000) evaluated the Malawi Rural Piped Water Scheme Program and reports that although the smallest and newest schemes were performing well 3 to 26 years after completion, overall almost half of the schemes were performing poorly. In a survey of 16 water points in a district in rural Zambia, Musonda (2004) found that ten years was the average age for functional handpumps, whereas semi-functional hand pumps were approximately 13 years old or more. Functional handpumps were those that typically served 360 people, whereas non-functional ones were those that had served about 506 people. This correlation between age and functionality of water supply systems is also reported by Moon (2006). Anecdotal evidence from the paper suggests that hand pumps require major rehabilitation after seven to eight years. Most pump and engine systems have significant maintenance costs within a few years but a few seem to work after 30 years, while gravity systems seem relatively unaffected by age.

Jiménez & Pérez-Foguet (2011) surveyed water points in 15 districts covering 15% of the rural population in

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Table 5 | Assessment criteria for reliability of urban water supplies

	Aderibigbe *et al.* (2008)	Akosa (1990)	Andey & Kelkar (2009)	Asian Development Bank (2007)	Ayoub & Malaeb (2006)	Baisa *et al.* (2010)	Caprara *et al.* (2009)	Gulyani *et al.* (2005)	Howard (2002)	Mycoo (1996)	Pan American Health Organization (2001)	Pattanayak *et al.* (2005)	Shah (2003)	Thompson *et al.* (2000)	Virjee & Gaskin (2010)	Widiyati (2011)	Zérah (1998, 2000, 2002)
Frequency of supply per week[a]	✓				✓												
Frequency of supply in days per week						✓	✓								✓		
Duration of supply in hours per day			✓	✓		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
Fraction of the time water is available		✓															
Frequency and length of service interruptions										✓							
Interruption in supply in the previous week									✓								
Pressure										✓							✓
Proportion of systems with intermittence											✓						
Proportion of population served by intermittent systems											✓						

[a]Unit not specified.

Table 6 | Assessment criteria for reliability of rural water supply

	Admassu *et al.* (2003)	Arnold *et al.* (2013)	Asian Development Bank (2009)	Bourgois *et al.* (2013)	Davis *et al.* (2008)	Hoko & Hertle (2006)	Jiménez & Pérez-Foguet (2011)	Kleemeier (2000)	Majuru *et al.* (2012)	Moon (2006)	Musonda (2004)	Norwegian Agency for Development Cooperation (2008)	O'Hara *ett al.* (2008)	Pan American Health Organization (2001)	Schweitzer (2009)	World Bank–Netherlands Water Partnership (2009)
Age of water supply system					✓										✓	✓
Breakdowns in previous 6 months					✓											✓
Breakdowns in study period									✓							
Down time		✓	✓		✓				✓							✓
Duration of supply hours per day			✓												✓	
Duration of supply days per week															✓	
Duration of supply interruptions in hours/day and days/week													✓			
Ease of operation of handpumps						✓					✓					
Flow rate																
Hours/days water was available per week		✓														
Lifespan of water system (proportion functional over a period of time)							✓			✓	✓	✓				

(*continued*)

Table 6 | continued

	Admassu *et al.* (2003)	Arnold *et al.* (2013)	Asian Development Bank (2009)	Bourgois *et al.* (2013)	Davis *et al.* (2008)	Hoko & Hertle (2006)	Jiménez & Pérez-Foguet (2011)	Kleemeier (2000)	Majuru *et al.* (2012)	Moon (2006)	Musonda (2004)	Norwegian Agency for Development Cooperation (2008)	O'Hara *ett al.* (2008)	Pan American Health Organization (2001)	Schweitzer (2009)	World Bank–Netherlands Water Partnership (2009)
Number of pumps in use at time of survey																
Proportion of taps supplying water at time of survey and preceding 3 months								✓								
Proportion of functional water sources at time of survey	✓	✓	✓	✓	✓		✓							✓		✓
Proportion of non-functional water sources at time of survey						✓										
Ratio of functional water systems in the population										✓						
Sources with major repairs within last month															✓	

Tanzania. They found that functionality rates did not vary greatly between hand pumps, gravity-fed systems and motorised pumping systems. Functionality of hand pumps dropped from 61% in the first five years of installation to 6% over a period of 25 years. In the same period, motorised pumps dropped from 77% to 13%, while gravity-fed systems dropped from 66% to 20%. The aggregated functionality for the three technologies was 35–47% of functional water points after 15 years. The authors conclude that generally 30% of water points became non-functional within the first five years of operation, after which period the decrease in functionality is at a slower rate.

In contrast, Bourgois *et al.* (2013) found that the performance of older systems is significantly better than that of newer ones. In their survey of water points in three districts in Sierra Leone, 73% of the water systems that were 22 years old were functioning at the time of the survey, compared to 40% of those that were a year old.

DISCUSSION

We explored definitions of and criteria used to assess water supply reliability, and have also noted some reports on the lifespans of various water supply technologies. We find that only four out of 33 papers in our review give explicit definitions of reliability. These definitions vary, but two common features appear to underlie these definitions: the functionality of the water supply system itself, and the extent to which it meets the needs of water users. The most common criterion used to assess water supply reliability in urban settings is the duration/continuity of supply in hours per day, whereas in rural settings the proportion of functional water systems is more commonly used. Results from four out of five papers reporting on the lifespans of water supply systems indicate a correlation between age and functionality; older systems are less likely to be functional. These results are contradicted in one paper which finds better functionality among older systems.

Before we discuss the implications of these findings, there are some limitations to the review that should be noted. Various terms synonymous with reliability are used in the literature, and although we have attempted to capture this variation in terminology in our search terms, we cannot exclude the possibility that some terms might have been missed. The papers retrieved must be considered in the light of this limitation. Although the literature reviewed is not exhaustive, it does cover a wide range of grey and published literature, including literature from key agencies in the water sector and results from important multi-country monitoring activities.

The two features underlying the definitions of reliability are reflective of the conundrum that characterises the assessment of other features of water supply. Should the definition and subsequent assessment be based on a *binary* approach of whether the supply is reliable, accessible or safe, or rather one that better reflects the *quality* of these water supply features?

The results indicate that current practice appears to favour assessment criteria based on the former in rural settings, and the latter in urban settings. The most common assessment criterion that is reported in rural settings is the proportion of water sources that are functional at the time of the survey. Given that the majority of papers reviewed are from sub-Saharan Africa where the majority of rural dwellers rely on handpumps (UNICEF/WHO 2011), it is likely that the assessment approach might have been shaped on this basis.

There are some challenges that the approach presents. First, although handpumps are quite common as the supply technology in rural areas, there are some countries that are making significant progress in 'moving up the service ladder' by providing piped technologies, either at communal points, within yards or within the home, South Africa being an example (see Lockwood *et al.* 2002; Tissington *et al.* 2008). In these settings water supply systems may not stop functioning completely, but gradually deteriorate in performance, and failure to take this into account would yield inaccurate estimates of the real situation on the ground.

Further, these 'snap-shots' of the proportion of functional systems do not always take into account whether the breakdown is short term, pending repair, or if the water source is completely non-functional (Lockwood *et al.* 2002; Koestler *et al.* 2010). The difficulty in operating handpumps that is noted as a significant problem in three papers perhaps alludes to the limitations of considering reliability of handpump supplies as a binary issue of whether or not the pump works.

The dominance of a particular assessment criterion in a particular setting should also not be assumed to mean that it is necessarily the most appropriate. For instance, although duration of supply appears to be the de facto assessment criterion in urban settings, adequate water pressure for instance, may also be important to water users. In the paper by Davis *et al.* (2008), the authors noted discrepancies in the reported duration of breakdowns, and attributed the discrepancies to respondents classifying events of low pressure that resulted in limited or no supply as breakdowns. Other studies have found that pressure fluctuations in piped systems can negatively affect water quality and subsequently health (Klasen *et al.* 2012; Lechtenfeld 2012). Taking this into account plus the range of assessment criteria found in this review, our findings point towards reliability of water supply being a multi-attribute concept, and this should be reflected in the definition. The adoption of a single assessment criterion also should not be assumed, and it is suggested that a multi-criteria assessment approach may be more appropriate.

As efforts to refine indicators used for global monitoring continue, we highlight that the primary challenge presented by water supply reliability is how to define and assess it in a framework that is cognisant of:

- the multi-attribute nature of water supply reliability;
- the various water supply technologies;
- the feasibility and cost of assessment;
- the role of water supply reliability as a predictor of health, social and economic outcomes.

Evidently, the development of this framework and subsequent definition and assessment criteria requires the continued collaborative efforts of those providing water supplies, funders and monitoring agencies. To this, we would add that understanding the value water users place on various attributes of reliability is necessary to better tailor assessment criteria that broadly recognise user perspectives. Among the literature we reviewed, little account is given as to how the criteria used to assess reliability were arrived at, nor how users define or perceive the concept of reliability.

CONCLUSION

Our review has shown that there is a great deal of variation in the definitions and assessment criteria used in literature on water supply reliability in developing countries. That said, there is some degree of commonality in the assessment criteria used, depending on the setting. Much of the literature reporting on urban settings report on duration of supply in hours per day, whereas in rural settings the proportion of functional water supply systems is more commonly reported.

Although these particular criteria dominate in the existing literature, care should be exercised to not assume that they are necessarily the most appropriate. First, the heterogeneity in the definitions and assessment criteria used is perhaps indicative of a multi-attribute nature of the concept of reliability. Failure to take this into account in the assessment process – regardless of setting – would likely yield an inaccurate depiction of the situation. Second, the reliance on a binary indication of functionality in rural settings may not take into account the changing landscape of water supply technologies in these areas, where supply systems may not necessarily fail altogether but perform at a sub-optimal level. Third, there is no indication that the perspectives of water users – those actually faced with unreliable water supplies – are taken into account when deciding upon assessment criteria. As ensuring reliability becomes increasingly critical in achieving the goal of universal access to water, the definition and assessment criteria for water supply reliability should be thoughtfully selected and employed.

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