World Health Organization

Domestic water quantity, service level and health

Second edition

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Preface

The publication of the World Health Organization (WHO) *Domestic water quantity, service level and health* in 2003 attracted renewed attention to the importance of these factors for health, well-being and prosperity. In its 2003 General Comment 15, the United Nations Committee on Economic, Social and Cultural Rights interpreted and comprehensively defined the right to water (UN, 2003). It listed availability, quality and accessibility of water as normative dimensions to judge water supply adequacy. WHO documents influenced the discussion on the human right to water – the first edition of this volume and the *Guidelines for drinking-water quality* are referenced in defining sufficient water quantity and safety, respectively, in General Comment 15. In 2010, 122 countries recognized the human right to water in United Nations Resolution 64/292 (UNGA, 2010a). A second resolution (Resolution 15/9) affirmed the legality of the right as derived from the right to an adequate standard of housing, and called Member States to take action towards realizing this right by maximizing their use of available resources (UNGA, 2010b).

In 2015, the 193 United Nations Member States approved Resolution 70/1 – Transforming our World: the 2030 Agenda for Sustainable Development – which laid out the 17 Sustainable Development Goals (SDGs) (UNGA, 2015). The SDGs are intended to promote sustainable and equitable development, and eradicate extreme poverty. Under SDG Goal 6, Target 6.1 calls for universal and equitable access to water by 2030.

The formulation of the SDGs was influenced by the United Nations human rights framework, with explicit references to the human right to water in the Transforming our World document: "In these Goals and targets, we are setting out a supremely ambitious and transformational vision. We envisage a world free of poverty, hunger, disease and want, where all life can thrive. We envisage a world … where we reaffirm our commitments regarding the human right to safe drinking water and sanitation and where there is improved hygiene …" (UNGA, 2015, paragraph 7).

By linking development with the human rights framework, the SDGs address poverty reduction and inequality. For water, this means shifting the emphasis: from increasing the proportion of the population with access to water, to attaining universal access to water and ensuring the quality of services, including use of sufficient water for health and development.

The term "service level", used in the first edition to signify proximity of access, is now interpreted by the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene to include accessibility, availability and quality for monitoring SDG Target 6.1. Given the changes in preferred terminology, "service level" is no longer used in the second edition of this document to indicate proximity of access. This is replaced by the term "accessibility", which is defined in this document.

In this second edition, new literature concerning water quantity, water accessibility and health is reviewed. The coverage has been extended to include the effects of water reliability, continuity and price on water use. Updated guidance is provided on domestic water quantity and accessibility, and their relationship to health.

The second edition of *Domestic water quantity, service level and health* continues to provide evidence and guidance that will be useful to policy-makers, health regulators and practitioners. It concerns water accessibility, its effect on water use, and the effect of both on health. It recommends targets for domestic water supply to ensure beneficial health outcomes.

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Abbreviations

AI	adequate intake
DALY	disability-adjusted life year
EFSA	European Food Safety Authority
IOM	Institute of Medicine of the United States National Academy of Sciences
NHMRC	National Health and Medical Research Council (Australia)
SDG	Sustainable Development Goal
UK	United Kingdom
UNICEF	United Nations Children's Fund
USA	United States of America
WaSH	Water, sanitation and hygiene
WHO	World Health Organization

Summary

Sufficient water is vital to human health, well-being and prosperity. Daily consumption of sufficient water is required to replenish body fluids and facilitate physiological processes. Water is also required for personal and domestic hygiene, and for productive and some recreational activities. Households with readily accessible water sources and that use more domestic water have significantly better health than households with more distant water sources that use less water.

This publication reviews evidence on adequate amounts of water for health and well-being. It recommends targets for domestic water supply to ensure beneficial health outcomes.

The amount of water used is largely determined by accessibility – that is, the time taken and distance travelled to collect water – and by continuity (availability all the time), reliability (availability when expected or needed) and price. Changes in the amount of water collected occur at access thresholds, as shown in Table S1. These thresholds can guide policies, plans and regulations that relate to water quantity.

A recommended minimum daily quantity of water for drinking is 5.3 litres (L)/person. This is the volume of water that should be accessible to ensure that lactating women engaged in moderate activity at moderately high temperatures – the population group with the highest physiological needs – remain hydrated. People living a sedentary lifestyle in temperate climates may require less, whereas those living in hot climates or engaging in strenuous work may require more. This water should be safe for consumption.

Insufficient empirical evidence is available to define a minimum quantity of water necessary for cooking, personal hygiene, food hygiene and other forms of domestic hygiene. Experience and expert opinion suggest that 20 L/person/day is often sufficient for drinking, cooking, food hygiene, handwashing and face washing, but not other hygiene practices. However, where demands for water are increased – for example, due to increased hand hygiene in response to outbreaks of disease – 20 L/day is likely to be insufficient, and in many cases running water from a tap will be necessary to support sufficient handwashing. This is a higher level of service than the indicator of water supply "on-premises" used to monitor Sustainable Development Goal (SDG) Target 6.1, which can also be satisfied by use of non-piped protected sources, such as a handpump in a yard. Piped water on-premises results in larger volumes of water used and can support improved hygiene. Good hygiene is also influenced by behaviours, knowledge and access to cleaning agents.

Table S1 indicates the quantities of water likely to be used by households and their adequacy for health needs, based on accessibility of the water supply. Where water supplies are not continuous or not reliable, households typically use less water. Less water is also used where prices exceed the level that households can afford.

Table S1. Summary of water access, adequacy and level of health concern

Access level and typical volumes of water used in the home[a]	Accessibility of water supply	Adequacy for health needs	Level of health concern[b]
Inadequate access (quantity collected can be below 5.3 L/person/day)	More than 1000 m in distance or 30 minutes total collection time	Drinking – cannot be assured Cooking – cannot be assured Hygiene – cannot be assured at the home,[c] compromising food hygiene, handwashing and face washing; other hygiene activities have to be undertaken away from the home	Very high
Basic access[d] (average quantity unlikely to exceed 20 L/person/day)	100–1000 m in distance or 5–30 minutes total collection time	Drinking – should be assured Cooking – should be assured Hygiene – food hygiene, handwashing and face washing may be assured; bathing and laundry cannot be assured at the home but may be carried out at water source	High
Intermediate access (average quantity about 50 L/ person/day)	Water delivered through one tap on- plot, or within 100 m or 5 minutes total collection time	Drinking – assured Cooking – assured Hygiene – all food hygiene, handwashing and face washing assured under non-outbreak conditions; enhanced hygiene during infectious disease outbreaks not assured; bathing and laundry at the home should also be assured	Medium
Optimal access (average quantity more than 100 L/ person/day[e])	Water supplied through multiple taps and continuously available	Drinking – all needs met Cooking – all needs should be met Hygiene – all food hygiene, handwashing and face washing needs should be met, including for bathing and laundry at the home, and household cleaning	Low

[a] Quantities used are likely to be lower if the primary water source is not continuous or reliable, or if water is unaffordable.
[b] Water safety is not included in this definition. Water safety is a health concern independent of water access and use.
[c] Where alcohol-based gels are used, they may contribute to hand hygiene.
[d] For the purposes of international monitoring, the Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) defines a "basic drinking water service" as use of an "improved drinking water source" with a total collection time of 30 minutes or less (round trip). A basic drinking-water service as defined by JMP approaches, but is not the same as, "basic access" as defined in this document. The JMP defines "safely managed water" – the indicator that measures SDG Target 6.1 – as an improved water source located on-premises, available when needed, and free from faecal and priority chemical contamination" (WHO & UNICEF, 2017). This is similar to "intermediate access" as defined in this document; however, the JMP definition accepts all improved sources, including those that are not piped, whereas intermediate access here is defined in terms of access to piped water.
[e] Based on http://www.waterstatistics.org/graph/18.

The public health gains from use of more water occur in three main increments:

- When households acquire basic access. This ensures that sufficient quantities of water are available for drinking, cooking, food hygiene, handwashing and face washing under most circumstances but not under situations demanding enhanced hygiene behaviours, including disease outbreaks. Bathing and laundry at the home are also not assured.
- When water becomes reliably available on-plot (intermediate access), especially where running water is available. This should provide sufficient water quantities for all personal hygiene, in addition to drinking, cooking and food hygiene. This level of service would, however, be insufficient to ensure that enhanced personal hygiene could be practised under disease outbreak conditions.
- When water becomes available within the home (optimal access) as running water through multiple taps. This level of service would be sufficient to cover all needs associated with drinking, cooking, personal hygiene and food hygiene. This level of service will ensure that there are adequate water quantities for enhanced personal hygiene practices under disease outbreak conditions, providing the water supply is reliable and continuous.

Households without basic access are unlikely to use the minimum quantity of water necessary for consumption. Ensuring that these households have reliable access to a basic water supply, and preferably intermediate access or higher, is a priority. Ensuring that everyone has at least an intermediate level of access is consistent with meeting SDG Target 6.1 and should be a priority for national policy in all countries. Further health improvements may occur in households attaining optimal access to water – for example, associated with increased use of water for hygiene because of ease of use, and the ability to use more water for gardening and productive purposes, leading to an increase in household nutrition and income.

Intermittent water service, whether reliable or not, is widespread, especially for piped supplies. Some evidence shows that households use less water when they receive fewer hours of service. Coping strategies include increased water storage or use of alternative sources. However, not all households can afford storage or other coping mechanisms, and alternative water sources may supply contaminated water.

The quality of evidence reviewed in this document is moderate.

- The evidence underpinning the definition of levels of accessibility is robust. Further research into the influence of reliability and price on water quantities used by households would improve our knowledge; however, it is unlikely that this would change the thresholds at which major shifts in water quantities used occur.
- The evidence underpinning recommended minimum volumes of water for drinking is moderate quality. This evidence is from established reference values and published literature. However, variation in requirements in different climates and for different activity levels suggests that further evidence is required to define more accurate hydration curves for civilian populations in low- and middle-income countries.
- There is insufficient evidence to derive a minimum quantity of water for cooking.
- It is difficult to draw a firm conclusion on the quality of evidence for water required for handwashing and face washing. There is no evidence to support an empirically derived estimate, but there is consistent expert opinion that the provision of 20 L/person/day can often allow handwashing and face washing, in addition to drinking, cooking and food hygiene. It is unlikely that further research would significantly change this conclusion.

1. Introduction

Domestic water – that is, water used by a household for drinking, food preparation and hygiene – is necessary for human life. Without water, life cannot be sustained beyond a few days, and inadequate water supplies lead to the spread of disease. The health of children under 5 years of age and adults over 50 years of age is most affected by environmental factors such as poor water and sanitation (Prüss-Ustün et al., 2016).

Diarrhoeal diseases attributed to poor water supply, sanitation and hygiene (WaSH) are estimated to have caused 829 000 deaths, representing 60% of all diarrhoeal deaths, and 49.8 million disability-adjusted life years (DALYs) in 2016 (Prüss-Ustün et al., 2019). The accessibility, availability and safety of domestic water influence diarrhoeal disease (Fewtrell et al., 2005; Waddington & Snilstveit, 2009; Wolf et al., 2014); diarrhoeal mortality among children has substantially decreased with decreasing exposure to unsafe WaSH (WHO, 2014). Other infectious and noncommunicable diseases are also associated with insufficient access to water. These include acute respiratory infections (Luby et al., 2005; Prüss-Ustün et al., 2019), and neglected tropical diseases such as trachoma and schistosomiasis (Grimes et al., 2014; Stocks et al., 2014; Strunz et al., 2014; Prüss-Ustün et al., 2019).

Diseases related to water supply are commonly classified by the mechanisms that control transmission and prevention. Table 1 presents a classification of water-related disease (adapted from White, Bradley & White, 1972).

Table 1. Classification of water-related disease

Class	Subclass	Examples
Waterborne	Infectious	Diarrhoeal diseases, infectious hepatitis
	Toxic chemicals	Arsenic, fluoride (at high exposures)
	Nutrient minerals	Fluoride (at moderate exposures)
Water access related	Superficial	Trachoma, scabies
	Intestinal	*Shigella* dysentery
	Respiratory	Pneumonia
	Hydration	Dehydration
	Injury and violence	Associated with water collection
Water based	Contact	Leptosporosis, *Naegleria fowleri*
	Ingested	Toxins from cyanobacteria
Water-related vectors	Water biting	Malaria
	Water breeding	Onchocerciasis
Engineered water system associated	Inhaled	Legionellosis, radon
	Ingested	*Mycobacterium avium* complex
	Contact	*Pseudomonas* spp.

Source: Adapted from Bartram & Hunter (2015).

The quantity of water that is available to, and used by, households influences several of these classes.

- Insufficient water can lead to water access–related diseases because sufficient quantities of water, along with soap, are required for good hygiene behaviours.
- Insufficient safe water may lead to consumption of contaminated water, leading to waterborne diseases.
- Water quantity also influences water-based diseases because more water for domestic use should reduce contact with surface waters where aquatic hosts live.
- Sufficient domestic water may reduce exposure to some vectors by reducing the need to use water sources where vectors may breed – for instance, the *Simulium* fly that transmits onchocerciasis. Exposure to other vectors – such as mosquitoes associated with the spread of malaria or dengue – may be increased if households need to store water or inadequate protection is provided against mosquitoes breeding in storage containers.

Inadequate water supplies contribute to poverty through the economic costs of poor health and household expenditure on water acquisition, through water purchase and the time and energy expended in collection (Hutton, 2012).

The importance of adequate water supply for human health and development has long been acknowledged. In 2010, it was reflected in the recognition of the human right to water by the United Nations General Assembly (UNGA, 2010a).

Target 6.1 of the Sustainable Development Goals (SDGs) calls for universal and equitable access to safe and affordable drinking-water by 2030. The indicator used for measuring progress towards the target is "population using safely managed drinking water services", which is defined as use of an "improved water source that is located on-premises, available when needed, and free from faecal and priority chemical contamination" (WHO & UNICEF, 2017). Although the indicator does not specify the quantity of safe water that should be accessible, households with this higher level of access will benefit because they use more water.

Norms for quantities of domestic water have been proposed for certain conditions and purposes. For instance, the Sphere Project recommends a minimum during humanitarian responses of 15 litres (L)/person/day, for drinking, basic hygiene and cooking (Sphere Project, 2018). Gleick (1996) suggested that the international community adopt a figure of 50 L/person/day, for drinking, cooking, bathing and sanitation, as a basic requirement.

The quantity of water transported to the home is related to its accessibility (Wang & Hunter, 2010; Subaiya & Cairncross, 2011; Cassivi et al., 2019), although this is not a linear relationship. Not all uses of water are necessarily performed on household premises. For example, laundry and bathing may be undertaken away from the home, and this should be borne in mind in interpreting and applying minimum values, and ensuring that sufficient water is available for all purposes.

It is important to distinguish water requirements for domestic purposes (which primarily influence health and productivity) from those for other purposes (e.g. agriculture, industry, commerce, transport, energy, recreation). Domestic supply typically constitutes a small component of total withdrawals from water resources (Gleick, 1993, 1996; WWAP, 2014).

The purpose of *Domestic water quantity, service level and health*, second edition, is to review evidence about the relationships between water quantity, water accessibility and health, and thereby support establishment of norms and recommendations for domestic water supply quantity and accessibility. It does not address the water requirements of population groups with special needs (e.g. athletes), in special settings (e.g. hydration needs during air travel or particular occupational settings), for specific needs in response to epidemics of disease (e.g. preparation of oral rehydration salts for cholera patients, or where enhanced hygiene is required), or for dehydration caused by alcohol consumption.

The authors have drawn on an extensive literature review. This review covered several topics, including the relationships between water quantity, water supply and health; the physiological requirements for water and hydration; and the use of water for domestic purposes. Key word searches were undertaken in Cambridge Scientific Abstracts (including Aqualine, Water Resource Abstracts and Bacteriology Abstracts), Google Scholar, Scopus and Medline. Recent systematic reviews, including their reference lists, on household water access and health were examined. A systematic review covering the period January 1970 to January 2013 was undertaken on the relationship between distance and time to a water source and the quantities of water collected by households. The systematic review by Cassivi et al. (2019) provided additional insight from the literature published between 2013 and early 2018.

2. Scope

The World Health Organization (WHO), in its *Guidelines for drinking-water quality*, defines domestic water as water used for all usual domestic purposes, including drinking, food preparation and hygiene (WHO, 2017). Requirements for adequate water apply to all these uses and not solely to consumption of water.

Distinguishing between uses of domestic water is useful in understanding minimum requirements and informing management. In 1972, the foundational study "Drawers of Water" examined the impact of water supply on health using household surveys and direct observation of household water use in urban and rural settings in Kenya, Tanzania and Uganda (White, Bradley & White, 1972). The authors of the study suggested three types of normal domestic use: consumption (drinking and cooking), hygiene (including basic needs for personal and domestic cleanliness) and amenity use (e.g. car washing, lawn watering). In 2001, a follow-up study of the same communities (Thompson, Porras & Tumwine, 2001) suggested a fourth category – productive use – to include brewing, animal watering, construction and small-scale gardening.

Use of water for consumption and hygiene has direct consequences for health, because these uses are related to physiological needs, and the control of diverse infectious and non-infectious diseases (waterborne, water access related and water based). Productive use of water has considerable indirect influence on human health, by sustaining livelihoods and helping to avoid poverty (Thompson, Porras & Tumwine, 2001; Renwick, Moriarty & Butterworth, 2007). Amenity use of water will usually not affect health. These different uses of water are discussed in the following sections; the quantity requirement for each is described, and implications for health are reviewed.

The dimensions of water service quality are reviewed by Kayser et al. (2013). Using the review by Kayser et al. (2013), this document reviews the evidence of the key dimensions of service quality (Table 2) that relate to the quantity of domestic water used.

Table 2. Key terms describing important dimensions of water service quality

Term	Definition	Units
Accessibility	The effort, expressed in terms of total time for collection (including waiting) and/or distance, that a person must expend to obtain water (see Table 11). The term "collection burden" is sometimes used as an alternative. This assumes that no other social, financial or cultural barriers restrict access. In this document, distance and time estimates are based on people collecting water on foot. Use of transportation systems may change the amount of water that can be collected when the water is off-plot.	Minutes or kilometres
Availability	The presence of water at a water source that can be collected when needed, but water may not be continuously available.	Proportion of time that water is present when individuals collect water
Reliability	The presence of water at a water source at expected or known times (usually every day), but water may not be continuously available.	Proportion of time that water is available when expected by users
Continuity	The availability of water at a water source without interruption. Continuity is not solely expressed in relation to users but is a system requirement to maintain safety and quality of water.	Proportion of time that water is available without interruption (e.g. hours/day, days/week, seasonally)
Affordability	The amount that households can routinely pay for water within their available resources without causing hardship.	Multiple measures, including ability to pay and willingness to pay. Affordability will be locally determined and depends on income, resources and costs of other essential items.

3. Water quantity requirements for consumption

Water plays a critical role in the functioning of the human body. It supports digestion of food; absorption, transport and use of nutrients; and elimination of toxins and wastes from the body (Kleiner, 1999). Water is consumed directly in beverages and ingested with food.

3.1. Health implications of dehydration

Water is lost through urine and faeces; from respiration and through the skin (insensible losses); and through sweat, especially at higher ambient temperatures and higher levels of activity. Sufficient water intake is necessary to replace losses and maintain the body's normal water balance. Dehydration occurs when the body receives insufficient water. It has adverse health effects that increase with greater dehydration.

With a 1% loss of body weight due to dehydration, the body triggers a thirst signal. As body weight loss increases to 5%, symptoms of dry mouth, discomfort, headache and impairment of work are experienced (WHO, 2005). A loss of 10% of body weight through dehydration can be fatal (WHO, 2005; EFSA, 2010). The United States National Institutes of Health (US NIH, 2002) defines mild dehydration as a loss of 3–5% of body weight, moderate dehydration as 6–10% loss of body weight and severe dehydration (a medical emergency) as 9–15% loss of body weight. Symptoms of severe dehydration include dark-coloured urine, dry skin, rapid heartbeat and/or breathing, sunken eyes, shock and unconsciousness (US National Library of Medicine, 2016). Mild dehydration can be reversed by increased fluid intake, which may be enhanced with salt replacement solutions. Severe dehydration requires more than simple fluid replacement – often food or other osmolar intake is needed – and may take up to 24 hours (Kleiner, 1999).

Dehydration may be acute – for instance, resulting from loss of body fluids because of severe diarrhoea, which can be fatal. Acute dehydration may also result from inadequate fluid replacement following water loss due to high temperature, both high and extremely low relative humidity, strenuous physical exertion and high altitude.

Dehydration may also be chronic (often mild), resulting from inadequate fluid replacement (Kleiner, 1999; Chan et al., 2002; Popkin & Rosenberg, 2010). A systematic review of chronic dehydration and health outcomes found strong evidence that adequate hydration lowers the risk of urinary stones (Armstrong, 2012). Kleiner (1999) reported that urinary stone formation is significantly increased when the urine volume excreted is less than 1 L/day, and urinary volumes exceeding 2–2.5 L/day prevent recurrence of stones in previously affected people. The European Association of Urology and the American Urology Association both recommend sufficient fluid intake to achieve a urine output of more than 2.5 L/day in the dietary treatment of patients with kidney stones, and the American College of Physicians recommends increasing fluid intake to ensure a urine output of more than 2 L/day (Ziemba & Matlaga, 2015). In a systematic review, Xu et al. (2014) found no clear threshold at which water intake is associated with reduced kidney stone risk. They concluded that any increase in water intake, even at low levels, was associated with reduced risk of kidney stones.

The review by Armstrong (2012) found hydration to be associated with reduced chronic kidney disease, fatal coronary heart disease, hypertension, venous thromboembolism, cerebral infarct and dental diseases, although the evidence was weak and based on few studies. One cross-sectional study in Australia reported that the risk of chronic kidney disease was significantly lower in participants in the highest quintile of fluid consumption (3.3 L/day) compared with the lowest quintile (1.7 L/day) (Strippoli et al., 2011). Johnson, Wesseling & Newman (2019) reviewed the evidence relating to chronic kidney disease in agricultural workers. They found that, in many of the regions where chronic kidney disease was reported, agricultural workers undertook hard physical work under hot conditions. However, several mechanisms could result in chronic kidney disease associated with dehydration, and it is not clear whether dehydration led to this disease, not least because it has not been reported in many of the hottest countries in the world (Johnson, Wesseling & Newman, 2019).

A study of the Adventist community in California, United States of America (USA), found a strong negative association between intake of water and the risk of fatal coronary heart disease for both men and women (Chan et al., 2002). Relative risks were 0.46 for men who had high-volume water intake (five or more glasses daily) and 0.54 for women who had medium intake (three to four glasses) compared with low water intake (two or fewer glasses). The authors did discuss potential confounding variables but found in most cases that the effect of drinking more water was retained when including cofounding variables in the multivariate models. The authors noted that strictly the results could be applied to the Californian Adventist community who do drink more water and less caffeinated and alcoholic beverages than the US averages. However, the authors did note that there are no biochemical or physiological differences from the general US population, and the Adventist community is subject to well-established risk factors for coronary heart disease to the same extent as the general population.

Popkin & Rosenberg (2010) reviewed 11 studies examining the adverse effects of dehydration on cognitive performance.

- Two studies found that, at 2.8% dehydration, there was a reduction in short-term memory, visual perception and hand–eye coordination (Cian et al., 2000, 2001).
- Another study reported adverse effects on cognition performance at 2% or greater dehydration (Gopinathan, Pichan & Sharma, 1988).
- At 2–2.6% dehydration, one study observed mild decreases in cognitive abilities (D'anci et al., 2009), and another found no significant decrease (Szinnai et al., 2005).
- Two studies found an increase in alertness following water intake, but neither showed a consistent effect on cognitive performance (Neave et al., 2001; Rogers, Kainth & Smit, 2001).
- Three studies that examined the effect of hydration on school children's cognition (Benton & Burgess, 2009; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009) reported mixed results and high heterogeneity in the methods used.

The authors concluded that low to moderate dehydration affects cognition, and that there was consistent evidence that dehydration reduced self-reported alertness (Popkin & Rosenberg, 2010).

In a further study of chronic effects of dehydration, Manz & Wentz (2005) found that sufficient hydration reduced hypertonic dehydration in infants and diabetic hyperglycaemia.

Most studies on the health effects of dehydration are from high-income countries. The effects of dehydration are unlikely to vary between countries or by income group, although the proportion of the population with insufficient access to safe water may vary systematically between low- and high-income settings. However, low- and middle-income countries are disproportionately subtropical and tropical in climate, where greater intake of water is likely to be required. Given the inconclusive evidence regarding the relationship between dehydration and health effects, further research is required in this area.

3.2. Published reference values

In their review, White, Bradley & White (1972) suggested that, in tropical climates, 2.6 L of water per day is lost through respiration, insensible perspiration, urination and defecation; more water is lost through sensible perspiration if hard work is performed and/or the temperature is higher. They did not differentiate these losses by gender or for children. Benelam & Wyness (2010) suggested that total water losses via respiration, urine, faeces and insensible loss range from 1.3–3.4 L/day for sedentary adults, rising to 1.9–8.6 L/day for adults who are physically active.

Taking into account fluid losses, White, Bradley & White (1972) suggested a daily minimum water consumption in tropical climates of around 3 L/person, although the volume of water loss suggests that this would provide a very small margin for variation between individuals and may not protect the most vulnerable. These authors provided estimates of water quantity needs at different temperatures and activity levels. They proposed that, at 25 °C with moderate activity in the sun (e.g. agricultural work), approximately 4.5 L would be required to maintain hydration. This would rise to about 6 L at 30 °C or when hard work in the sun is undertaken at 25 °C. Under extreme conditions of hard work at high temperatures in the sun, the authors noted that this figure could rise to as much as 25 L/day. The proportion of water intake from food could vary substantially; in rare cases (e.g. pastoralists using milk as the primary food), food potentially provides 100% of the fluid requirement.

The Institute of Medicine of the United States National Academy of Sciences (IOM) published water intake levels – termed adequate intake (AI) levels – based on estimates from observations and experimental evidence, and reflecting median water intake of healthy US and Canadian individuals living in temperate climates, which account for total water intake (in water, beverages and food) (IOM, 2005; Table 3). For adult males and females, the recommended AI for total water intake is 3.7 and 2.7 L/day, respectively (IOM, 2005). The IOM recommends an additional 0.3 L/day and 1.1 L/day for pregnant and lactating women, respectively.

Table 3. Adequate intakes of beverages and total water by life stage and gender for healthy people in temperate climates, USA and Canada

Life stage	Males		Females	
	Beverages (L/day)	Total water (L/day)	Beverages (L/day)	Total water (L/day)
0–6 months	0.7	0.7	0.7	0.7
7–12 months	0.6	0.8	0.6	0.8
1–3 years	0.9	1.3	0.9	1.3
4–8 years	1.2	1.7	1.2	1.7
9–13 years	1.8	2.4	1.6	2.1
14–18 years	2.6	3.3	1.8	2.3
>19 years	3.0	3.7	2.2	2.7
Pregnancy	NA	NA	2.3	3.0
Lactation	NA	NA	3.1	3.8

NA: not applicable.
Source: Adapted from IOM (2005); used with permission of The National Academies Press from *Dietary reference intakes for water, potassium, sodium, chloride and sulfate*, Institute of Medicine (US), copyright 2005; permission conveyed through Copyright Clearance Centre Inc.

Similar nutrient reference values have been published for Australia and New Zealand (NHMRC, 2006; Table 4), which also apply an AI approach. The European Food Safety Authority (EFSA) collated and reviewed published guidelines and recommended water intake levels (EFSA, 2010; Table 4); its reference values also apply an AI approach for different age groups, taking into account the same physiological needs as those published in the USA, Australia and New Zealand, and reference data from surveys in European countries on water intake. Some countries tie guideline values to energy requirements, which may better account for body size and activity level (Popkin & Rosenberg, 2010), as shown in Table 4.

In the WHO *Guidelines for drinking-water quality* (WHO, 2009, 2017), guideline values for chemical contaminants are normally based on the assumption of a 60 kg adult consuming 2 L of water per day. Where they are based on a specific susceptible life stage, figures of 1 L/day for a 10 kg child or 0.75 L/day for a 5 kg bottled-fed infant are used. The WHO International Programme on Chemical Safety (IPCS) uses reference values for volumes of fluid intake in deriving its guidance, based on reference body weights of 70 kg for adult males, 58 kg for adult females and an average of 64 kg (IPCS, 1994). More recently, the IPCS has adopted detailed recommendations on mean drinking-water intakes for infants based on body weight (Hubal et. al, 2014), as shown in Table 5.

Typically, most water intake (approximately 80%) comes from beverages and water rather than food (Benelam & Wyness, 2010; EFSA, 2010). However, populations consuming water-rich foods may receive larger proportions of their total water intake from food. For instance, a study in Bolivia found that up to 50% of participants' total water intake came from food, primarily water-rich fruits (Rosinger & Tanner, 2014).

Table 4. Recommended intakes of total water, and drinking-water and beverages, selected European countries, EFSA, Australia and New Zealand

Country or organization	Year	Life stage	Recommended value: total water	Recommended value: drinking-water and beverages
Belgium	2009	Child	Detailed recommendations based on body weight	
		Adult	2500 mL/day	1500 mL/day
Austria, Germany, Switzerland	2008	Infant	1.5 mL/kcal/day	
		Adult	1.0 mL/kcal/day	
		Elderly	>1.0 mL/kcal/day	
France	2001	Adult	25–35 mL/kg body weight/day	
Denmark, Finland, Norway, Sweden	2004	Child	Detailed recommendations based on body weight	
		Adult	30 mL/kg body weight /day or 1mL/kcal/day	
		Elderly (>65 years)	1500 mL/day	
		Lactating woman	Additional 600–700 mL/day	
Netherlands	1989	Adult (fasting)		1000 mL/day
		Adult		1500 mL/day
		Elderly		1700 mL/day
EFSA	2010	Infant (6–12 months)	800–1000 mL/day	
		2–3 years	1100–1300 mL/day	
		4–8 years	1600 mL/day	
		9–13 years (boys)	2100 mL/day	
		9–13 years (girls)	1900 mL/day	
		Adult female	2000 mL/day	
		Adult male	2500 mL/day	
		Elderly female	2000 mL/day	
		Elderly male	2500 mL/day	
		Pregnant woman	Additional 300 mL/day	
		Lactating woman	Additional 600–700 mL/day	
Australia, New Zealand	2006	0–6 months	700 mL/day	700 mL/day
		7–12 months	800 mL/day	600 mL/day
		1–3 years (all)	1400 mL/day	1000 mL/day
		4–8 years (all)	1600 mL/day	1200 mL/day
		9–13 years (boys)	2200 mL/day	1600 mL/day
		9–13 years (girls)	1900 mL/day	1400 mL/day
		14–18 years (boys)	2700 mL/day	1900 mL/day
		14–18 years (girls)	2200 mL/day	1600 mL/day
		Adult male	3400 mL/day	2600 mL/day
		Adult female	2800 mL/day	2100 mL/day
		Pregnant woman (14–18 years)	2400 mL/day	1800 mL/day
		Pregnant woman (19–50 years)	3100 mL/day	2300 mL/day
		Lactating woman (14–18 years)	2900 mL/day	2300 mL/day
		Lactating woman (19–50 years)	3500 mL/day	2600 mL/day

Sources: Adapted from NHMRC (2006); EFSA (2010); used with permission of John Wiley and Sons from *Scientific opinion on dietary reference values for water*, European Food Safety Authority, EFSA Journal, 8(3), 48, copyright 2005; permission conveyed through Copyright Clearance Centre Inc.

Table 5. Recommended mean drinking-water intake by age group

Age group	Intake (mL/kg body weight/day)
Birth to <1 month	137
1 to <3 months	119
3 to <6 months	80
6 to <12 months	53
1 to <2 years	27
Time–weight average for birth to <12 months	78
>21 years (adults)	16

Source: Adapted from Hubal et al. (2014).

In 2003, the United States Army updated its recommendations on water intake per hour in relation to heat categories and activity intensity to prevent heat injury (Kolka et al., 2003) (Table 6). The volumes suggested (expressed as consumption per hour) are much higher than other recommendations. The activity intensity categories are based on military activities, some of which are comparable to civilian activities. For example, manual agricultural work and collection of 20 L of water from an off-plot water source would both be at least as strenuous as moderate work as defined by Kolka et al. (2003). With moderate activity, water losses at low temperatures can be similar to those at high temperatures, as a result of increased respiratory losses associated with activity (Freund & Young, 1996).

Table 6. Recommended water intake by activity intensity and temperature

Activity intensity	Water intake (L/hour)			
	25.6–27.7 °C	27.8–29.4 °C	29.5–32.2 °C	>32.2 °C
Easy work (walking hard surface at 4.0 km/hr, carrying <13.6 kg)	0.47	0.47	0.71	0.94
Moderate work (walking loose sand at 4.0 km/hr or hard surface at 5.5 km/hr, carrying <18.1 kg)	0.71	0.71	0.71	0.94
Hard work (walking loose sand at 4.0 km/hr or hard surface at 5.5 km/hr, carrying ≥18.1 kg)	0.71	0.94	0.94	0.94

Source: Adapted from Kolka et al. (2003).

There is no recommended upper limit for water intake. However, intake of too much water can lead to hyponatremia, which can result in kidney and heart failure (Panel on Dietary Reference Intakes, 2005). The United States Army recommends that hourly fluid intake should not exceed 1.5 quarts (1.42 L) and that daily intake should not exceed 12 quarts (11.35 L) (Kolka et al., 2003).

3.3. Specific population groups

Particular population groups have specific hydration requirements. Young children, pregnant or lactating women, the elderly, people suffering from acute or severe diarrhoea, the terminally ill, those fasting (particularly in climates with high temperatures) and athletes may have substantively different requirements from population averages. The evidence and guidance presented here are appropriate for these groups, apart from athletes; athletes differ from the general population in the cause and management of dehydration, and their hydration would typically also include salt replacement.

The water content of adult bodies is 50–60% of body weight, whereas in infants it is 75% (EFSA, 2010). Infants and children also have a higher surface area to body mass ratio, a higher rate of water turnover, and less effective sweating mechanisms than adults (IOM, 2005; Benelam & Wyness, 2010). As a result, losses of water from the bodies of small children are proportionately considerably greater than for adults: 15% of fluid per day as opposed to 4% (Kleiner, 1999). These higher losses explain why a child requires more fluid per kilogram of body weight to replace lost fluid than an adult (Kleiner, 1999). Low-birthweight infants require greater fluid replacement per kilogram of weight than other infants, as a result of increased evaporation through the skin (Roy & Sinclair, 1975; Ellis, 2011).

Pregnant women require additional fluid to ensure that fetal needs are met, as well as providing for expanding extracellular space and amniotic fluid. The IOM suggests an extra 0.3 L/day of total water intake (0.1 L/day from beverages) during pregnancy (IOM, 2005). The Australian and New Zealand Nutrient Reference Values suggest an additional 0.2–0.3 L/day (depending on age group) for pregnant women, based on median intakes of pregnant women from surveys in the USA.

Lactating women also have additional water requirements, to replenish water used in milk production. A study in the Amazon found that significantly more lactating women were clinically dehydrated than nonlactating women, although the rates of dehydration among both groups were high (78% and 50%, respectively) (Rosinger, 2015). The IOM suggests an additional 1.1 L/day of total water intake (0.9 L/day from beverages) for the first 6 months of lactation (IOM, 2005). In Australia and New Zealand, it is proposed that an additional 0.7 L/day is required for lactating women, based on the fluid replacement requirement for average daily milk production and the proportion of breast milk that is water. In some countries, women who are pregnant or lactating undertake moderate activity in high temperatures. They will therefore require both the additional fluid requirements associated with such activity and the additional requirements associated with pregnancy and lactation.

The elderly may not require greater volumes of water, but may be at risk of dehydration as a result of reduced thirst sensations (Benelam & Wyness, 2010; Popkin & Rosenberg, 2010). A study among older adults in the USA who were hospitalized, found that concomitant diagnosis with dehydration was significantly associated with higher mortality rates (Warren et al., 1994). Renal function decreases with age, as kidneys lose their ability to concentrate urine, suggesting an increasing water requirement to maintain renal function (IOM, 2005; EFSA, 2010). Benelam & Wyness (2010) reported numerous health benefits related to adequate water intake in elderly adults, including decreased falls and constipation.

Patients taking medications may need to consume more water. HIV patients taking certain antiretroviral medications are advised to consume an additional 1.5 L/day to reduce harmful side effects (NASCOP, 2006). Individual volume recommendations vary, based on the specific treatment. For patients suffering from severe diarrhoea (e.g. cholera), the UNICEF Cholera Toolkit (UNICEF, 2013) recommends an allowance of 10 L/patient/day for oral rehydration.

For the terminally ill, a review by Jackonen (1997) cited a range of benefits of dehydration and of hydration. Benefits of dehydration include lower levels of distress, lower awareness of pain and reduced requirements for urination; benefits of hydration include preventing malnourishment, prolonging life and avoiding health problems such as renal failure. Terminally ill patients often receive medical hydration (administered via the intravenous or nasogastric routes, or as nutrition), which has little impact on volumes of water required in a general domestic supply.

Fasting is practised in diverse cultures and religions. During a typical 12-hour fasting period, an estimated 1% of body mass may be lost as water by a sedentary individual in a temperate climate (Maughan & Shirreffs, 2012). This will increase with longer fasting, higher temperatures and activity. Acute intermittent dehydration can occur if water is not replenished, which may lead to headache (Leiper, Molla & Molla, 2003). There is no evidence that intermittent dehydration during fasting has detrimental health effects, but it is difficult to separate the effects of fasting from food and the effects of dehydration (Leiper, Molla & Molla, 2003).

3.4. Water requirements to maintain hydration

The requirement for humans to maintain adequate hydration should inform policy, programming and professional practice. However, the definition of the "absolute minimum" quantity of water to sustain hydration remains elusive, as it depends on individual physiological factors, climate, activity and diet.

The reference values published by the IOM (for the USA and Canada; Table 3), EFSA (for Europe; Table 4), and the National Health and Medical Research Council (NHMRC; for Australia and New Zealand; Table 4) follow a similar approach using similar evidence; the result is a relatively small range of values. This could be translated into a global reference value based on the upper limit for males and females; however, we suggest that taking a median is more appropriate to reflect the variability in requirements for different people and environments. This approach results in a recommended intake of water (from all sources) to maintain hydration in temperate climates of 3.2 L/person/day for men and 2.7 L/person/day for women.

Households with the least access to water supplies are more likely to be engaged in at least moderate activity, often in moderately high temperatures. There are no studies that provide clear empirical data on the amounts of water consumed in such households. Despite the obvious difficulties in comparing activity categories for the military and civilians, recommendations for the military offer the best basis for estimating the water required. Using the values for the military presented by Kolka et al. (2003), civilians undertaking moderate work at moderately high temperatures (around 28–32 °C) for 5–8 hours each day (median 6.5 hours) should consume 3.5–5.7 L of fluid per day, from all sources. This will rise with higher temperature or more strenuous activity.

Thus, the quantity of water required for hydration (total direct ingestion, including food) should be a minimum of 3.2 L/day for adults in temperate climates (based on the higher requirement for males) (Table 7). Using the median time engaged in moderate work at moderately high temperatures noted above, this increases to 4.6 L/day. Longer periods of moderate physical activity at higher temperatures, more strenuous work or more extreme heat may substantially increase the intake of water required. These figures apply to all individuals. They encompass the range in which beneficial impacts on prevention of coronary disease and kidney stone occurrence appear likely, and are at the lower end of requirements to prevent recurrence of kidney stones.

Table 7. Recommended intake of water for drinking

Category	Water intake (L/person/day)		
	Sedentary, temperate	**Moderate physical activity at warm temperature (6.5 hours at 28–32 °C)**	**Lactation, moderate physical activity at warm temperature**
Female adult	2.7	4.6	5.3 (0.7 L additional; median of published values)
Male adult	3.2	4.6	Not applicable
Recommended minimum volume	**3.2**	4.6	**5.3**

Note: Required volumes will be higher under conditions of strenuous physical activity and high temperatures.

To account for the needs of lactating women, many of whom are in the group with least water access and undertaking moderate activity in moderately high ambient temperatures, a further 0.7 L/day (the median of published values from the IOM, EFSA and the NHMRC) is added to the minimum quantity under conditions of moderate work at moderately high temperatures. This results in an estimated minimum water quantity for fluid required for hydration (via both direct consumption and food) of 5.3 L/person/day, based on the needs of the most vulnerable (lactating women undertaking physical activity at moderately high temperatures). Needs may be considerably greater for people in hot environments or engaged in very strenuous physical activity.

As some hydration needs are met through water obtained from food, the figure of 5.3 L/person/day can be interpreted using two approaches. The first is to assume that the water supply should be able to meet all hydration needs. The second approach is to assume that some of the total water for hydration is derived from food (Benelam & Wyness, 2010; EFSA, 2010) and that therefore domestic water supply needs to meet only about 80% of the minimum quantity. The former approach is adopted here because the proportion of fluid obtained from food varies substantially with diet and culture – from negligible to 100% of hydration needs – and some fraction of water in food derives from the water supply (e.g. in the case of dried foods such as rice and noodles).

3.5. Types of fluid intake for hydration

The benefits and disbenefits derived from specific types of fluid consumed are unclear. For instance, Kleiner (1999) suggested that drinking diuretics such as coffee may lead to mild dehydration; however, a systematic review of caffeine ingestion and total body water found no evidence that moderate caffeine consumption (250–300 mg/day) resulted in fluid loss (Maughan & Griffin, 2003). Subsequent reviews corroborated this conclusion (Benelam & Wyness, 2010; EFSA, 2010).

Grandjean et al. (2000) suggested that there is no significant difference between consumption of different beverages with regard to hydration status. Tucker et al. (2015) examined the 24-hour hydration status of 34 adult males given different combinations of fluids: water; water and cola; water and diet cola; and water, cola, diet cola and orange juice. Based on serum osmolality and bioelectrical impedance (total body water), there was no difference in hydration status between the different beverage combinations. However, this study examined effects over the course of 24 hours, and it is not known whether hydration would be affected over a longer period.

Chan et al. (2002) reported a statistically significant positive association between consumption of fluids other than water and risk of coronary disease among women consuming more than five glasses/day of fluids other than water, compared with those consuming less than two glasses/day (average total beverage intake of eight glasses/day). The point estimates of relative risk did not change even when adjusting for established factors for coronary disease. The association in men was not statistically significant. An attempt was made to identify the impact of specific fluids on coronary disease, but this was not possible for several reasons: daily intake of juices and sugared drinks was generally low; the consumption of caffeinated beverages was not statistically significant; and the intake of soy milk was close to zero. The authors noted that the population studied consumed less alcohol and caffeine than average. Although this study does not provide information on risks for specific fluids, it does suggest that consuming water may have benefits over other fluid intake. Chapman et al. (2018) found that consumption of high-fructose caffeinated beverages after exercise at high temperatures increased biomarkers of acute kidney injury.

3.6. Water requirements for cooking

Water is essential for preparing food. It is used in cleaning foodstuffs (e.g. washing salad materials) and in transmitting heat (e.g. cooking in boiling water), and is deliberately incorporated into some foodstuffs during cooking (e.g. rice). Defining requirements for water for cooking is difficult, because they depend on the diet and the roles of water in food preparation. However, most cultures have a staple foodstuff, which is usually some form of carbohydrate-rich vegetable or cereal. According to the Food and Agriculture Organization of the United Nations, cereals and starches account for about 40% of daily calories in “western” diets and up to 70% elsewhere (Latham, 1997).

Guidance on nutrition promotes eating a balanced diet with a range of foodstuffs. Some guidance suggests the number of servings per day of different foodstuffs (e.g. the Food Pyramid in the UK; Safefood, 2020). Others base recommendations on total calorie intake for various categories of activity level and diets, with recommended portions of different food groups (e.g. USDHHS & USDA, 2015). Very few low- and middle-income countries have established dietary guidelines, and the guidelines that do exist are sometimes difficult to find (Fischer & Garnett, 2016). Information on diets is therefore skewed to high-income countries, where dietary guidance is typically more concerned with reducing overnutrition than undernutrition, and European and North American populations rather than African or Asian populations.

A minimum requirement for water supply should include sufficient water to prepare an adequate quantity of the staple food. An example can be provided for rice, which is the most widely used staple food worldwide. To prepare rice using the absorption method (i.e. only sufficient water to cook the rice is added), about 0.35 L of water is required for 170 g/person/day of rice (recommended by USDHHS & USDA, 2015), depending on the type of rice. These estimates do not consider cultural preferences in terms of how rice should be prepared or its consistency, or the increased energy requirement for people undertaking hard physical labour. These factors may substantially increase the amount of water required for cooking, as may preferences for different types of a staple (e.g. brown rice, long-grain rice, basmati rice). Different quantities of water may be required for other staples, such as maize/corn meal, millet, sorghum, wheat flour, potatoes, sweet potato, yam, cassava and plantains (Latham, 1997).

The amount of water used in cooking varies substantially (Wong 1987; Cairncross & Kinnear, 1992; Gilman et al., 1993; Cairncross & Cliff, 1987; Reddy 1999; Thomson, Porras & Tumwine, 2001; Adekalu, Osunbitan & Ojo, 2002; Milton et al., 2006; Cronin et al., 2008; Fan et al., 2013; Ishaku et al., 2013). However, available studies present data in different ways – for example, combining estimates for drinking and cooking, and using different units for estimated daily use (household, person). In addition, different studies have used different and sometimes unclear methods to collect data, and some studies have lacked clarity on the type of water source. These issues preclude use of these studies in a meta-analysis. The studies also refer to use rather than need. Nonetheless, it is clear that in many settings substantially more water is used than estimated above and, in some settings, less, although lower estimates tend to be from older studies and more water-stressed environments.

Given the weak available evidence, it is not possible to derive a minimum quantity of water required for cooking.

4. Water access and quantity requirements for hygiene

To protect health, water is needed for personal and domestic hygiene – including handwashing, bathing and laundry, and food preparation. There is evidence from some settings for similar management of water for consumption and for food hygiene, which is distinguished from water used for personal and domestic hygiene and laundry (Elliott et al., 2017).

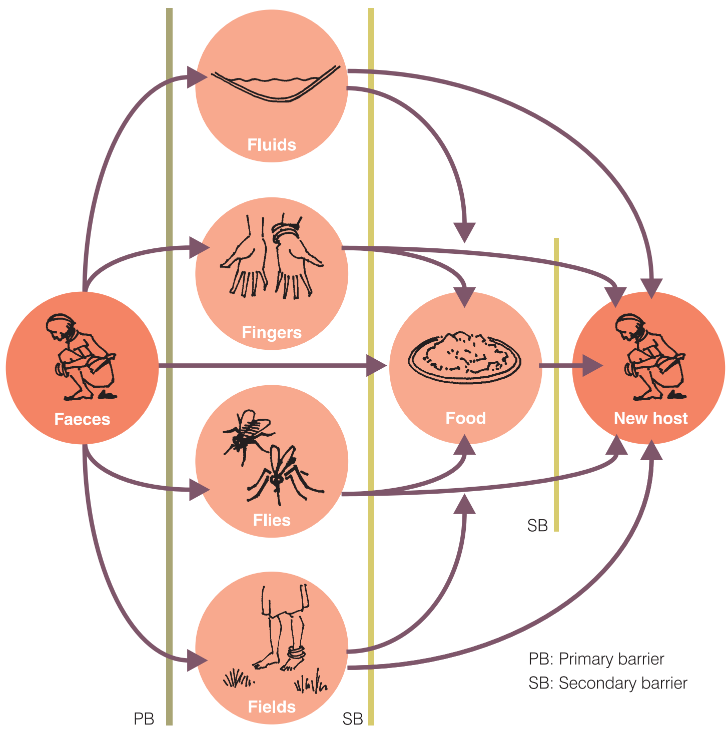
4.1. Impacts of water access and quantity on health

Poor hygiene may in part be caused by insufficient domestic water (White, Bradley & White, 1972). Diseases linked to poor hygiene include diarrhoea and other diseases transmitted through the faecal–oral route; skin and eye diseases, including trachoma; respiratory infections; and diseases related to infestations, such as louse- and tick-borne typhus (Bartram & Hunter, 2015; Prüss-Ustün et al., 2019).

4.1.1. Hygiene and diarrhoea

Diseases transmitted through the faecal–oral route (Fig. 1) include infectious diarrhoea, typhoid, cholera and infectious hepatitis. Faecal–oral diseases are typically acute (with a possibility of death), and some have sequelae. Transmission may occur through consumption of contaminated water and food, as well as person–person contact (White, Bradley & White, 1972).

Fig. 1. Transmission of disease via faecal–oral route



Source: WELL (1998), adapted from Kawata (1978); copyright 1998, London School of Hygiene and Tropical Medicine, UK, and Water, Engineering and Development Centre, Loughborough University, UK, via Creative Commons (CC BY-NC-ND 4.0).

Factors other than water and sanitation facilities, and hygiene behaviours influence diarrhoeal disease. For example, breastfeeding protects against diarrhoeal disease, independent of other interventions (Quigley, Kelly & Sacker, 2007; Lamberti et al., 2011).

Based on a number of systematic reviews (Esrey et al., 1991; Esrey, 1996; Fewtrell et al., 2005; Waddington & Snilstveit, 2009) on endemic diarrhoeal disease, Bartram & Cairncross (2010) concluded that reasonably well designed improvements in one or more of water supply, water quality, sanitation or hygiene are likely to reduce diarrhoeal disease by one third. It has been suggested that improving the availability and quantity of drinking-water is more important than improving the quality of water (Fewtrell et al., 2005; Waddington & Snilstveit, 2009). However, relative effects are context dependent. In addition, it is difficult to draw a firm conclusion from these reviews because of the relative scarcity of high-quality studies on either water quantity or source water quality, and the likely misclassification of exposure to unsafe water in studies on water source quality.

A meta-regression estimated that transitioning from basic piped water to safe piped water of continuous availability would reduce diarrhoea by 73–79% (Wolf et al., 2014). This was based on a single high-quality study (Hunter, Ramirez Toro & Minnigh, 2010), although the results were noted as being consistent with evidence from high-income countries. Wolf et al. (2014) found that transitions from unimproved water sources or community-level improved water sources to a basic piped supply were associated with far smaller reductions in risk than the transition to safe piped water of continuous availability, suggesting that increased water availability alone offers little benefit in reducing diarrhoeal disease. The meta-regression was updated in 2018 (Wolf et al., 2018), with similar findings.

Reliability of supply influences health. Hunter, Zmirou-Navier & Hartemann (2009) modelled the role of reliability of supply in reducing risks of disease, concluding that interruption in supply of even short duration greatly increases risks to health. Ercumen, Gruber & Colford (2014), in a systematic review of piped distribution deficiencies and gastrointestinal disease, showed a significant association between gastrointestinal disease and water outages – both outages in continuous water supplies and chronic outages in intermittent supplies. Most included studies were from high-income countries. Jeandron et al. (2015) found an association between smaller volumes of water supplied through a piped system, including periods of no production from the treatment plant, and cholera incidence in Ulvira in the Democratic Republic of the Congo.

Several epidemiological studies relate intermittent water supplies to outbreaks of diarrhoeal disease (Kumpel & Nelson, 2016). Using global data on intermittent water supplies, Bivins et al. (2017) applied a quantitative microbial assessment model to estimate disease burden associated with *Campylobacter*, *Cryptosporidium* and rotavirus as risk proxies for infections with bacteria, protozoa and viruses, respectively. They estimated that intermittent water supply accounts for 17.2 million infections, causing 4.52 million cases of diarrhoea, 109 000 diarrhoeal DALYs and 1560 deaths each year (Bivins et al., 2017). In contrast, Ercumen et al. (2015) found no statistically significant association between intermittent water supply and diarrhoea in an urban area of India; however, the association was significant among lower-income children under 5 years of age. Households managing intermittent supply by storing water face a greater likelihood of contamination than those taking water directly from the source (Shaheed et al., 2014; Shields et al., 2015).

Table 8 summarizes results from systematic reviews and meta-regressions on reductions in diarrhoeal disease morbidity associated with improved water sanitation and hygiene.

Table 8. Reduction in diarrhoeal disease morbidity from water sanitation and hygiene in low- and middle-income countries from published systematic reviews and meta-regressions

Factor and reference	All studies			Rigorous studies[a]		
	N	% Reduction	Effect size (95% CI)	*N*	% Reduction	Effect size (95% CI)
Water and sanitation						
Esrey et al. (1991)	7	20	–	2	30	–
Sanitation						
Esrey et al. (1991)	11	22	–	5	36	–
Fewtrell et al. (2005)	2	32	0.68 (0.53–0.87)	–	–	–
Waddington & Snilstveit (2009)	6	37	0.63 (0.43–0.93)	–	–	–
Water supply						
Esrey et al. (1991)	7	27	–	5	20	–
Fewtrell et al. (2005)	6	25	0.75 (0.62–0.91)	–	–	–
Waddington & Snilstveit (2009)	8	2	0.98 (0.89–1.06)	–	–	–
Water quality and quantity						
Esrey et al. (1991)	22	16	–	2	17	–
Water quality						
Esrey et al. (1991)	7	17	–	4	15	–
Fewtrell et al. (2005)	15	31	0.69 (0.53–0.89)	8	39	0.61 (0.46–0.81)
Clasen et al. (2007)[b]	33	35	0.65 (0.59–0.71)	–	–	–
Arnold & Colford (2007)	10	29	0.71 (0.58–0.87)	–	–	–
Schmidt & Cairncross (2009)	4	NA	1.09 (0.98–1.22)	–	–	–
Waddington & Snilstveit (2009)	31	42	0.58 (0.50–0.67)	–	–	–
Hygiene						
Esrey et al. (1991)	6	33	–	6	33	–
Fewtrell et al. (2005)	11	37	0.63 (0.52–0.77)	8	45	0.55 (0.40–0.75)
Waddington & Snilstveit (2009)	17	31	0.69 (0.61–0.77)	–	–	–
Handwashing						
Ejemot et al. (2009)	4	32	0.68 (0.52–0.90)	–	–	–
Aiello et al. (2008)	24	31	0.69 (0.58–0.81)	13	26	0.74 (0.62–0.90)
Cairncross et al. (2010)	10[c]	47	0.53 (0.37–0.76)	–	–	–
Ejemot-Nwadiaro et al. (2015)	22	28	0.72 (0.62–0.83)	–	–	–
Multiple[d]						
Fewtrell et al. (2005)	5	33	0.67 (0.59–0.76)	–	–	–
Waddington & Snilstveit (2009)	7	38	0.62 (0.46–0.83)	–	–	–

[a] Studies described as "rigorous" in Esrey et al. (1991) and "excluding poor quality studies" in Fewtrell et al. (2005); excludes studies that lacked randomization, did not apply "masking", and used a unit of analysis different from the unit of randomization in Aiello et al. (2008).
[b] As reported in Waddington & Snilsveit (2009).
[c] In intervention studies only.
[d] Joint water, sanitation and hygiene, or health education interventions in Fewtrell et al. (2005); water supply and sanitation/hygiene or water quality, and sanitation/hygiene in Waddington & Snilstveit (2009).

Several studies from low- and middle-income countries have looked at the role of distance to water source in diarrhoeal disease incidence. In a meta-analysis, Wang & Hunter (2010) found that risk of diarrhoea was statistically associated with distance to water source. In response, Subaiya & Cairncross (2011) commented that there was insufficient evidence to define an association between distance to water source and diarrhoea because of methodological flaws in study design and risk of bias. They did, however, note that the largest study with the least methodological flaws showed a linear relationship between distance to water source and diarrhoeal morbidity. Households in Viet Nam with piped water connections had significantly less diarrhoea and used more water than households using improved water sources located off-plot (Brown et al., 2013). Modelling by Pickering & Davies (2012), using data from Demographic and Health Surveys in 26 countries in sub-Saharan Africa, showed that a 15-minute reduction in walk time was associated with an average 41% reduction in diarrhoea prevalence in children. The reduction was greatest among children with sanitation at home. In Burkina Faso, per capita quantity of available water and access to water on-plot were statistically associated with less child diarrhoea (Dos Santos, de Charles Ouédraogo & Soura, 2015). A walk time of 30 minutes or more to the water source was statistically associated with higher risk of diarrhoea, but walk times of 5–30 minutes were not significantly associated with risk of diarrhoea (Dos Santos, de Charles Ouédraogo & Soura, 2015). Aluisio et al. (2015) found that access to water on-plot was not significantly protective against childhood diarrhoea. Nygren et al. (2016) reported a significantly higher incidence of moderate to severe diarrhoea in households in rural Kenya where water collection time exceeded 30 minutes and where rainwater had not been collected in the previous 2 weeks than in households whose collection time was less than 30 minutes.

4.1.2. Hygiene and child growth

Child growth has been statistically linked to household cleanliness (Lin et al., 2013), suggesting the importance of water availability and hygiene behaviour. A Cochrane review (Dangour et al., 2013) found few studies that examined the role of water quantity on child height outcomes. Three studies showed that children from households receiving improvements in water supply had significantly better child weight and height outcomes than children not receiving the intervention (Schlesinger et al., 1983; Huttly et al., 1990; Fenn et al., 2012). One study conducted in Bangladesh found no relationship between increased water supply and child growth (Hasan et al., 1989).

A study in rural Lesotho found synergistic protective effects of water and sanitation on child height (Esrey, Habicht & Casella, 1992). Height-for-weight score was more strongly associated with latrine use than with water quantity. A cohort study in Sudan found that children with indoor water supplies and private sanitation had significantly higher height-for-age scores than children lacking water and sanitation, but having either water or sanitation alone was not protective (Merchant et al., 2003).

A study in Pakistan found that household access to a greater quantity of water was protective against stunting (van der Hoek, Feenstra & Konradsen, 2002); storage containers linked to household connections represented the most protective level of service. A study in Peru found the volume of water storage to be significantly associated with better child growth; children from households using cement cisterns or 50-gallon drums for water storage were significantly taller than children from households using small containers such as pots, pans, barrels or buckets for water storage (Checkley et al., 2004). Children from households with piped water connections had marginally better height outcomes than children lacking such connections, but benefits were greatest among children with water connections, sewerage and large storage containers (Checkley et al., 2004).

A systematic literature review that investigated the health effects of on-plot water access found that households with water on-plot experienced less diarrhoea and helminth infections, and better child height outcomes (Overbo et al., 2016). Most rigorous included studies included socioeconomic status in the statistical analyses (Overbo et al., 2016). Studies by Humphrey et al. (2019), Luby et al. (2018)

and Null et al. (2018) found no association between WaSH interventions and child linear growth, although none specifically assessed water availability.

4.1.3. Handwashing and other hygiene behaviours

Prost & Négrel (1989) found that reducing the time taken to collect water (including journey and waiting time) from 5 hours to 15 minutes resulted in 30 times more water being used for child hygiene. A study in Mali showed that households less than 100 m from their water source used more water to wash children's faces (mean 9.7 L/child/day) than households more than 100 m from their water source (mean 8.6 L/child/day) (Schemann et al., 2002). Studies in Tanzania found distance to water source to be statistically associated with clean child faces (West et al., 1989; Lynch et al., 1994).

The quantity of water available to the household affects water use for hygiene and frequency of hygiene behaviour. In a study in Peru, Gilman et al. (1993) reported a positive relationship between the quantity of water available in the home and the frequency of handwashing in a shantytown. In Kenya, Tanzania and Uganda, Thompson, Porras & Tumwine (2001) found that households with piped water used more water for bathing, washing and drinking/cooking than households without piped water (for bathing, 17.4 L and 7.3 L, respectively). Following a water supply intervention in Swaziland, more households reported washing hands after defecating, bathing twice a day, washing clothes more than once a week, and having sufficient water to wash hands (Peter, 2010). Before the intervention, the majority of households used less than 5 L for bathing; after the intervention, the majority of households used 5–10 L for bathing (Peter, 2010).

Hygiene behaviours are influenced by a range of factors, including reliability of water sources. In rural China, households with intermittent water supply on-plot did not have different water use behaviours from households using public taps, but households with continuous piped water supply used significantly more water, including for drinking, personal hygiene, showering and laundry (Fan et al., 2013).

The timing of handwashing may be important for its health benefits; therefore, sufficient water should be readily available throughout the day. Key times for transmission of faecal–oral diseases are cited as before preparing food (Stanton & Clemens, 1987), before eating food (Birmingham et al., 1997), before feeding children (Iyer et al., 2005), after defecation (Curtis, Cairncross & Yonli, 2000; Luby et al., 2011) and after cleaning a child's anus (Iyer et al., 2005). Researchers in Guatemala asked mothers to wash hands after using the latrine; after changing a nappy; before cooking or eating; before feeding children; before touching water for drinking or cooking; and before going to bed. They found that washing at these times required 20 L/household/day of water for handwashing (Graeff et al., 1993, as cited in Curtis, Cairncross & Yonli, 2000). Hygiene recommendations for prevention of diseases with respiratory and contact spread, such as timing and frequency of handwashing, are rarely cited or discussed (see section 4.1.6 for a summary of studies on hygiene and respiratory infections).

A number of studies suggest that handwashing with water alone removes some bacteria from hands, but is less effective than handwashing using soap or other agents (Khan, 1982; Cairncross, 1993; Ghosh et al., 1997; Oo et al., 2000). Burton et al. (2011) showed that handwashing with soap and water reduced bacterial contamination on hands substantially more than handwashing with water alone. Similarly, Amin et al. (2014) reported that washing hands with water significantly reduced contamination, but was less effective than washing with soap or soapy water. Hoque & Briend (1991) showed that some reductions in contamination were found when washing with water alone, although these reductions were less than when using soap; use of alternative rubbing agents (mud or ash) provided the same benefits as soap. Scrubbing time affects hand decontamination: a laboratory-based study in the USA found that increasing scrubbing time from 15 to 30 seconds led to greater reductions in bacteria. However, a field study in Bangladesh found no significant differences between 15-second and 30-second scrubbing times (Amin et al., 2014). In a small laboratory study of the efficacy of six hand hygiene protocols (soap and water, alcohol-based hand sanitizer and four formulations based on chlorine, including high-test hypochlorite) in removing *E.coli* and bacteriophage Phi6, Wolfe et al. (2017) found little difference between protocols on removing or inactivating these organisms and that all were efficacious.

In a study of handwashing in Bangladesh, rinsing hands with 0.5–2 L of water significantly reduced the presence of thermotolerant (faecal) coliforms on study participants' hands (Hoque, 2003). In a study in Tanzania, the quantity of water used for handwashing was the only hygiene factor statistically associated with enteric virus presence on hands: doubling the quantity of water used for handwashing led to a two-fold reduction in the odds of a study participant having enteric virus on their hands (Mattioli et al., 2014).

In a study in Bangladesh, Luby et al. (2011) found that washing both hands with water only before food preparation was protective against child diarrhoea, but washing at least one hand with soap led to greater diarrhoea reduction than using water alone on both hands. After defecation, washing hands with soap was statistically associated with less diarrhoea; washing hands with water only, ash or mud had no statistical effect (Luby et al., 2011). Handwashing with or without soap before feeding children, before eating, or after cleaning a child's anus following defecation were not significantly associated with child diarrhoea. Alam et al. (1989) found that children whose mothers washed hands with ash or mud experienced significantly less diarrhoea than children whose mothers washed hands with water alone.

4.1.4. Hygiene and trachoma

A systematic review and meta-analysis showed that face washing at least once daily and bathing at least once daily were both significantly protective against active trachoma (Stocks et al., 2014). Reviews by Stocks et al. (2014) and Stelmach & Clasen (2015) identified several studies reporting significant associations between water quantity and trachoma indicators; however, similar numbers of studies found no statistical relationship. Stocks et al. (2014) did not conduct a meta-analysis for quantity of water use and trachoma because of insufficient studies, but seven of 16 studies reported significantly lower odds of trachoma among households using more water for washing, and four of six studies reported significantly lower odds of trachoma among households using more water in total. The quantities of water found to be protective against trachoma included use of:

- 10 L/person/day (Kupka, Nižetič & Reinhards, 1968)
- 40 L/person/day (Ketema et al., 2012)
- 60 L/person/day (Mahande, Mazigo & Kweka, 2012)
- 5000 L/person/month (165 L/person/day) (Luna et al., 1992)

- 2 L/household/day for face washing (Mahande, Mazigo & Kweka, 2012)
- 10 L/child/day for washing (Faye et al., 2006)
- 6.43 L/child/day for washing (Bailey et al., 1991).

In many studies, distance from primary water source to the home appears to be the most important water supply factor influencing trachoma. In a review by Esrey et al. (1991), four studies demonstrated a median reduction of 30% in trachoma incidence with shorter distance to the home; two studies found no relationship. Several studies in reviews by Prüss & Mariotti (2000) and Stocks et al. (2014) reported significantly lower odds of trachoma when the distance to water source was <1000 m (Hoechsmann et al., 2001) or the travel time was ≤30 minutes (Taylor et al., 1989; Montgomery, Desai & Elimelech, 2010; Ketema et al., 2012), but this relationship was not observed in all included studies. The distances and travel times to water source found to be protective against trachoma included:

- walk time of 5 minutes (Tielsch et al., 1988)
- walk time of 16 minutes (Zerihun, 1997)
- walk time of 30 minutes (West et al., 1989)
- walk time of 120 minutes (Hsieh et al., 2000)
- household connection (Assaad, Maxwell-Lyons & Sundaresan, 1969)
- distance of 200 m (Mathur & Sharma, 1970).

Polack et al. (2006) found that active trachoma was associated with increased collection time for water (including both travel time to the source and collection time), but there was no association between active trachoma and the quantity of water collected. They also found that active trachoma was associated with the proportion of water allocated within the household for hygiene, suggesting that behaviour may be more important than volume of water collected.

Distance to source was found to be significantly associated with trachoma prevalence as a continuous variable (Schemann et al., 2002; Vinke & Lonergan, 2011) and in quartiles (Baggaley et al., 2006). Stocks et al. (2014) found that distance to water source over 1000 m was not significantly associated with trachoma in a meta-analysis. They suggested that this could reflect the small number of studies analysed; alternatively, the use of 1000 m as the criterion may not adequately capture the health and hygiene benefits of increased water availability.

A linear relationship between distance to water source and trachoma prevalence has been suggested (Schemann et al., 2002; Baggaley et al., 2006; Polack et al., 2006; Vinke & Lonergan, 2011). However, other reviews (Esrey et al., 1991; Prüss & Mariotti, 2000; Stocks et al., 2014; Stelmach & Clasen, 2015) indicate that only large differences in water quantity, corresponding with different service levels, are significant in relation to the incidence of trachoma. West et al. (1991) concluded that per capita water availability is not associated with either trachoma or facial cleanliness. Bailey et al. (1991) showed that lower volumes of water used for washing children's faces are associated with trachoma, but total volume use per capita is not. It has also been suggested that the value placed on the use of water for hygiene is protective against trachoma, rather than source proximity and per capita water collection (West et al., 1989; Bailey et al., 1991; Zerihun, 1997).

Most studies of the incidence of trachoma suggest that hygiene behaviour is a key determinant, as well as access to improved sanitation (Stocks et al., 2014). For instance, facial cleanliness is important and appears to function independently of water quantity (West et al., 1989). Having a clean face and face washing at least once a day were significantly protective in a meta-analysis by Stocks et al. (2014). Clustering of cases within communities is also important, as is the presence of siblings with trachoma within households (West et al., 1991, 1996; Harding-Esch et al., 2008). Factors such as cattle ownership (Hsieh et al., 2000; Faye et al., 2006; Ngondi et al., 2007) are also important in rural areas, and sanitation and garbage disposal are important in both urban and rural areas (West et al., 1996; Zerihun, 1997; Jip et al., 2008). This is supported by a review of the evidence concerning environmental and facial cleanliness interventions in integrated trachoma programmes (Emerson et al., 2000).

4.1.5. Hygiene and skin infections

The evidence regarding the amount of water used and skin infections is mixed, and interpretation of results is difficult because diverse skin infections are often grouped together.

In a study of influences on skin disease in rural Tanzania, Gibbs (1996) found that household density and socioeconomic conditions were important determinants of the incidence of transmissible skin disease. The study compared two villages, one with a water source within 20 minutes and the other with a water source that was 46 minutes from the village. Distance to water source was not significantly associated with skin disease. Similarly, a study in Mozambique found no statistical difference in skin infection prevalence between a village where households had proximal water sources, bathed children daily and used 14 L/person/day of water and a village where households had a 90-minute round trip to collect water, bathed children less frequently and used 8 L/person/day of water (Cairncross & Cliff, 1987). In contrast to these studies, Hennessy et al. (2008) found that regions in Alaska, USA, with higher coverage of on-plot water access had significantly fewer hospitalizations due to skin infections than regions with lower coverage of on-plot access.

Other studies report that hygiene behaviour can be important for skin infections. Children in Tanzania living in households with more hygienic conditions had lower prevalence of scabies (Masawe, Nsanzumuhire & Mhalu, 1975). In Mali, Mahé et al (1995) found that scabies and severe pyoderma were significant public health problems. Washing with plain soap (Luby et al., 2005) or antibacterial soap (Luby et al., 2002) lowered impetigo incidence among children in Pakistan, and less frequent washing was statistically associated with impetigo in South Africa (Verweij et al., 1991). In Gambia, children with impetigo were more likely to be from households that used less water for washing (average 2.69 L/child/day) than children without impetigo (5.71 L/child/day) (Bailey et al., 1991). A study in two Panamanian islands found that residents with household taps used more water (7.1 L/person/day vs. 2.3 L/person/day) and had lower rates of impetigo and scabies than residents on an island where water was collected from streams (Ryder et al., 1985).

4.1.6. Hygiene and respiratory infections

Children in households receiving plain soap and handwashing promotion in Pakistan had significantly less pneumonia than children not receiving the intervention, suggesting that handwashing is protective (Luby et al., 2005). This is supported by a meta-analysis that estimated a 24% reduction

(95% CI: 6–40%) in respiratory infection from handwashing, although the meta-analysis included studies of poor quality (Rabie & Curtis, 2006). Respiratory infections were significantly lower in regions of Alaska, USA, with higher on-plot water access than in regions with lower on-plot water access, where more households collected water from communal sources (Hennessy et al., 2008). However, this effect was not observed in two other Alaskan studies (Singleton et al., 2003; Bulkow et al., 2012) nor in a study in Panama (Ryder et al., 1985). However, handwashing and other hygiene behaviours were not analysed in these studies, so the effects of on-plot water access on hygiene behaviour cannot be ascertained.

Evidence from Nepal suggests that, in cold climates, the influence of water on hygiene may be modified by the availability of heated water rather than all water. A review of data on water supply access and diarrhoeal and skin diseases showed that the incidence of hygiene-related diseases was much higher than average in districts that had very cold seasons for part of the year (Howard & Pond, 2002). It was suggested that the absence of hot water inhibits good hygiene, a finding in line with research into emergency responses in countries with distinct cold seasons (Buttle & Smith, 2004).

4.1.7. Other health considerations, including HIV/AIDS

Bed-bound patients being cared for at home require additional water for hygiene, and regular cleaning of bed linens and clothes (Ngwenya & Kgathi, 2006). Ngwenya & Kgathi (2006) observed use of an additional 20–80 L/day in households in Botswana caring for individuals living with HIV/AIDS. As sufficient water was not always available, caregivers reduced the frequency of bathing patients and laundry, and collected water from alternative sources (buying and storing water). Each of these coping mechanisms was considered to be potentially detrimental to the health of both the caregivers and the people living with HIV/AIDS, through poorer hygiene, exposure to lower-quality water and contamination of stored water. For households with off-plot water supplies, the time and cost for collecting additional water reduced the time available for direct care of sick individuals and other purposes.

A systematic review on WaSH interventions and people living with HIV found that piped water, treated water and reliable water reduced intestinal parasites in people living with HIV; however, the studies reported only type of water source, not water quantity (Yates et al., 2015). West, Hirsch & El-Sadr (2013) concluded that improvements in water supply would probably improve HIV outcomes and alleviate burdens for caregivers. A systematic review of WaSH interventions to reduce diarrhoeal disease among people living with HIV and AIDS found no studies that looked at water supply or sanitation improvements (Peletz et al., 2013). The 10 included studies related either to household water quality (nine studies) or promotion of handwashing (one study).

On-premises non-piped water sources and off-premises water sources all require water carriage, which may be beyond the capacities of people with physical disability or illness. Some conditions also reduce people's ability to participate in water collection, and to perform personal and domestic hygiene behaviours. Using data from five cross-sectional surveys undertaken in Bangladesh, India, Cameroon and Malawi, Mactaggart et al. (2018) found no difference in access to water supplies and sanitation between households with members with disability and households without. However, in Cameroon and India, households with a member with disability were more likely to spend more than

30 minutes collecting water. Differences within households were more marked: people with disability reported difficulties collecting water themselves, and difficulties were most marked for people with more severe impairments. For a case–control study in Guatemala, although people with disability had no greater difficulties in accessing water than those without, largely because of having water piped into the home, they did experience greater difficulties in hygiene (Kuper et al., 2018). Older people with disability reported more difficulties than younger people.

Groce et al. (2011) noted that social barriers exist for people with disability accessing water sources because of discrimination and stigma. Similarly, people suffering from HIV or caring for those with HIV, and those affected by some other diseases may be denied use of certain water sources by other community members (Yallew et al., 2012).

4.2. Impacts of water access on noncommunicable disease

In households that do not have continuous on-plot water supplies, it is often women and children who fetch water (Graham, Hirai & Kim, 2016; Geere & Cortobius, 2017). This involves carrying water in containers from the source to the household, unless a means of transport such as a wheelbarrow, bicycle or animal-drawn cart is available. In a systematic review, Geere et al. (2018a) found moderate quantitative and strong qualitative evidence that carrying water is associated with pain, physical injury, fatigue, perinatal health problems and violence against vulnerable people, including rape and physical abuse. Vulnerable people include older adults, women, children and people with, or caring for, someone with disability (Groce et al., 2011; Wrisdale et al., 2017). There is strong qualitative evidence that stress is associated with water carriage (Geere et al., 2018a), and that lack of access to water and sanitation is related to a range of stressors that adversely affect mental health and well-being (Bisung & Elliott, 2016).

Geere et al. (2018a) suggested that the pain and injury reported to be associated with water carriage in many studies are symptoms of musculoskeletal disorders. For example, a multi-country cross-sectional field study reported a correlation between water carriage and areas of pain associated with spinal axial compression (Geere et al., 2018b). The association was stronger for respondents who carried water on their heads than for other carrying methods (Geere et al., 2018b). A study of 24 sites in low- and middle-income countries showed water insecurity to be strongly associated with increased risk of injury during water fetching (Venkataramanan et al., 2020). Although there is little longitudinal research to confirm a causal relationship, the evidence of association between water carriage and typical musculoskeletal symptoms or self-reported injury, together with the high and growing burden of musculoskeletal disorders (from any cause) in low- and middle-income countries, indicates that many people will experience pain and face difficulty if they carry water home from off-plot sources (Hoy et al., 2014a, b). Although women and children who carry water commonly also carry other loads (Porter et al., 2013; Kadota et al., 2020), increasing access to on-plot water supplies will reduce the burden of pain and disability attributable to water carriage and may therefore also reduce the overall incidence of musculoskeletal disorders and disability.

Numerous products have been piloted to alleviate the physical burden of water carriage. However, there are challenges in changing behaviours and marketing new technologies (Martinsen et al., 2019), and such products do not address the underlying problem of water access and insecurity (Melles, de Vere & Misic, 2011; Jepson et al., 2017; Wutich et al., 2017).

Reducing the physical burden of water collection has other potential health benefits. In a study including 49 Multiple Indicator Cluster Surveys from 41 countries, Geere & Hunter (2020) showed that women from households with at-house supply and where no one had to collect water were more likely to give birth in a healthcare facility, had increased uptake of antenatal care, had a reduced risk of childhood deaths, and were less likely to leave a child under the age of 5 at home alone, compared with households with people collecting water away from home.

4.3. Water requirements for food hygiene

Raw foods, such as fruits and vegetables, can be contaminated on their exterior with pathogens and chemicals such as pesticides. It is therefore important for households to clean such foods before consumption. Food preparation and eating surfaces, and utensils also require cleaning before use. Washing foods in a 200 ppm chlorine solution can reduce the surface bacteria concentration by 1–2 log units, depending on the type of food (Beuchat, 1998; WHO, 2006). Risk factors for food contamination include hygiene practices of those preparing the food, use of contaminated water in food preparation, and contamination of raw foodstuffs through the use of facael sludge as a fertilizer or untreated wastewater for irrigation. Hot climates, poor storage practices, insufficient cooking time, and time elapsed between meal preparation and consumption support growth of microbes on food.

Defining a volume of water sufficient for food hygiene is complex. In a study of 32 households without an in-house water supply in a Peruvian shantytown, Oswald et al. (2008) reported a mean of 6.4 L/household/day (range 0.0–13.0) used to wash raw foods; household size was not reported. Cairncross & Kinnear (1992) estimated that households in two communities in Sudan used 1.5–3 L/person/day for washing utensils and food, but did not separate the two activities. Other studies do not report a category of water used for washing foods. Given the lack of specific evidence, it is not possible to define a minimum quantity of water for food hygiene. Determining the water required for effective food hygiene is an important research question.

4.4. Water requirements for effective personal and food hygiene

Insufficient evidence is available to calculate a minimum quantity of water necessary for personal and food hygiene. As a result, in this document, we draw on experience from practitioners, and these typically consider food and personal hygiene together. Effective hygiene is determined by multiple factors, among which water is not necessarily the most critical – they include behaviours, timing of hygiene practices, the presence and use of soap, and sanitation. To act as a positive driver for improved hygiene, higher service levels are necessary: at least one tap on-premises from which water is available continuously, or adequate coping mechanisms such as household storage if supply is intermittent.

Water quantity is only an absolute constraint on personal and food hygiene if water is available in only very small quantities, and is reserved for drinking and cooking. Such situations may be found when water sources are remote from households and total collection time is excessive. In most settings, experience suggests that around 20 L/person/day is likely to be adequate for basic food hygiene, handwashing and face washing, in addition to drinking and cooking, but not other hygiene practices. This is not an empirically proven volume of water, and there are numerous examples of situations where poor hand, face and food hygiene is found despite these levels of service.

Where demands for water for hygiene are increased – for example, due to increased frequency of handwashing in response to outbreaks of disease – 20 L/day is likely to be insufficient; often, running water from a tap is necessary to support sufficient handwashing (Howard et al., 2020). When enhanced personal hygiene is required, it is likely that even an intermediate level of access will not provide sufficient water to fully protect health. In water-scarce regions, guidance should be provided on avoiding excessive wastage of water. For example, water can be turned off after wetting hands – ideally by using touchless methods such as motion-activated sensors – and then turned on to rinse hands after lathering, to conserve water. Where other forms of handwashing stations are used, guidance should be provided on how to manage release of water without increasing the risk of disease transmission through handling of the tap (or other withdrawal utensil).

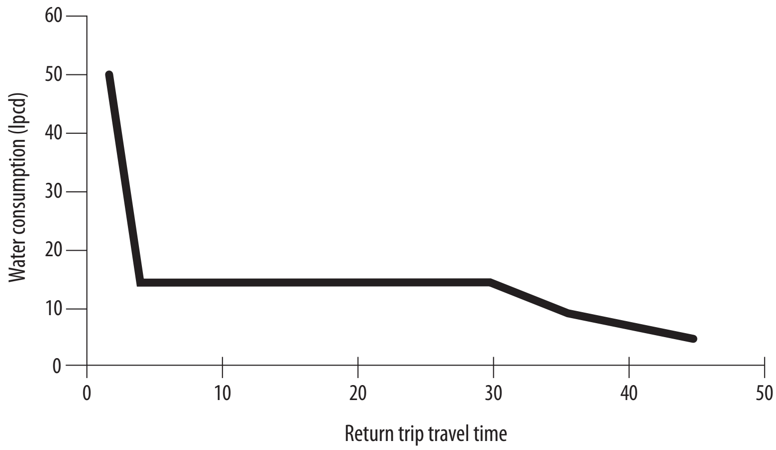
5. Factors affecting the quantity of domestic water used

5.1. Quantity and accessibility: how much do people use and what are the links?

A number of studies have examined the effects of water accessibility on household water use, particularly in relation to proximity and collection time. Cairncross & Cliff (1987) studied two villages in rural Mozambique: one had a standpipe with an average collection round trip of 10 minutes, and the other had a distant water source that required a round trip of more than 5 hours. They found the average quantity of water used in the first village to be 12.30 L/person/day, compared with 3.24 L/person/day in the second village. The additional water was primarily used for hygiene-related purposes. The difference in collection time points to the influence of differences in levels of access – in this case, between inadequate access and basic access (see Table 11 in section 6.1).

A general relationship between water accessibility and collection behaviour has been suggested by Cairncross (1987), as shown in Fig. 2.

Fig. 2. Travel time versus consumption



lpcd: litres per capita per day.
Note: Travel time is in minutes.
Source: WELL (1998), after Cairncross (1987); copyright 1998, London School of Hygiene and Tropical Medicine, UK, and Water, Engineering and Development Centre, Loughborough University, UK, via Creative Commons (CC BY-NC-ND 4.0).

This proposed relationship suggests that, as the time taken to collect water exceeds a few minutes (typically 5 minutes or 100 m from the home), the quantities of water collected decrease dramatically. A plateau then operates within a distance of around 100–1000 m or 5–30 minutes collection time. Beyond this, quantities of water decrease further.

Cassivi et al. (2019) undertook a systematic review of the relationship between water accessibility (determined using either distance or time) and water quantity at the household level. They found an inverse relationship between the distance or time taken to collect water and the quantity of water collected, but noted that imprecise measures in several of the studies and metrics that could not be compared between studies limited their ability to confirm the water plateau shown in Fig. 2. Of 11 studies, seven reported a relationship between accessibility and water quantity, but only four of these applied statistical tests to assess the effect: all found an association that was significant at the 95% level. The remaining four studies showed no relationship between accessibility and water quantity at the household level. However, these were in settings where this was explicable: households had access to water within a short distance, gained only marginal improvement in accessibility with increasing collection time, or used multiple water sources, including sources based at the household.

Rhoderick (2013) undertook a systematic review of the relationship between distance, time and domestic water quantity. Searches were undertaken in PubMed, Embase and Global Health for papers published between January 1970 and January 2013, with no language restriction in the search, although only those in English were included in the full review. Included studies were undertaken in low- and middle-income countries, and reported time or distance and water quantity. The searches yielded 4687 papers after removing duplicates. Of these, 132 met the criteria for full text screening, and 16 met the inclusion criteria. A further eight papers were identified through a hand search, yielding a final set of 24 studies.

In the systematic review by Rhoderick (2013), time was considered as total collection time, including travel to and from the source, and time waiting at the source. Of the 20 included studies that examined the relationship between water collection distance or time and domestic water quantity, eight found no relationship, and 12 found an inverse relationship between distance or time and quantity. Studies did not consistently observe a significant decrease in water quantity beyond 30 minutes collection time and/or 1000 m distance. Of the included studies, five compared households that had on-plot water supplies with households that did not; all of these reported higher average quantities of water use in households with on-plot water supplies, and almost all reported at least a doubling of per capita water use. Although the quality of the evidence was poor, the findings of the review support the general relationship between accessibility (distance to source and round-trip collection time) and quantity shown in Fig. 2. However, the findings suggest that the graph shape and specific break points differ by setting. A similar finding was reported by the subsequent systematic review by Cassivi et al. (2019).

Results might differ between studies for several reasons, including differences in data collection methods, household use of multiple water sources, and at-household versus at-source water use, especially for bathing and laundry. Many studies conflate the ideas of distance and time to source or use one measure as a surrogate for the other, making it difficult to examine the variables separately. This has particular implications for studies involving households that are close to water sources but experience long queue times (Aiga & Umenai, 2002).

In addition to the effect on domestic water use, long distances to water sources and long queueing times present opportunity costs and physical burdens for households. Reducing the collection burden for households yields benefits even if there is no proportionate increase in water use (the plateau of Fig. 2). Cairncross & Cliff (1987) observed that women with a closer water source used their excess time for rest and housework. Women reported use of time saved on activities such as income generation and education of their children (Arku, 2010).

Where water is delivered through at least a single tap on-plot, water use increases substantially; further increases are found when water is piped into the home and is available through multiple taps. The findings from a study from Jinja, Uganda (Table 9), illustrate this (WELL, 1998): average use of water when it is piped inside the home is relatively high (155 L/person/day), but 50 L/person/day is used when water is supplied to a yard. Thompson, Porras & Tumwine (2001) found similar per capita water use by households in Kenya, Tanzania and Uganda with a tap on premises (regional average 57.8 L/person/day; range 45.4–68.3). When water access is off-plot, average use drops to roughly one third the average use at a yard tap and one tenth that of households with water piped inside the home.

Table 9. Average water intake, Jinja, Uganda

Type of supply	Average quantity (L/person/day)	Access level (as defined in this document)
Traditional sources, springs or handpumps	15.8	Inadequate or basic[a]
Standpost	15.5	Inadequate or basic[a]
Yard tap	50	Intermediate
House connection with multiple taps	155	Optimal

[a] Specific access level could not be determined because collection distance or time was not reported.
Source: Adapted from WELL (1998); copyright 1998, London School of Hygiene and Tropical Medicine, UK, and Water, Engineering and Development Centre, Loughborough University, UK, via Creative Commons (CC BY-NC-ND 4.0).

Although there are few published studies, there appears to be little variation in the quantities used when water is supplied through a yard level of access and little increase beyond 50 L/person/day. This may be because this level of access does not permit easy use of water-hungry devices, or that households find that efforts expended to obtain water remain sufficiently high to limit overall quantities used (Burt & Ray, 2014). Once water is supplied through multiple taps within the home, much more water is used because physical effort to obtain water is largely eliminated. In practice, the amounts used by households may vary, depending on how many water-using appliances are used and their efficiency.

Overall, the volume of water used in the home is primarily sensitive to improvements in access level. Increases in water used occur at distinct thresholds of access.

5.2. Laundry and bathing: on- and off-plot use

Minimum requirements for domestic water should include sufficient water for laundry and bathing, which help to protect health. Laundry and bathing may be carried out at the home or off-plot – for example, at a water source, with corresponding reduction in the volume of water transported to the home for these purposes.

Studies in Kenya, Tanzania and Uganda suggest that the quantities of water used for bathing (including handwashing), and washing of clothes and dishes are affected by the level of water access (Thompson, Porras & Tumwine, 2001). For households using water sources outside the premises, an average of 6.6 L/person was used for washing dishes and clothes, and 7.3 L/person for bathing. In contrast, households with a domestic connection to piped water supply used an average of 16.3 L/person for washing dishes and clothes, and 17.4 L/person for bathing. The authors suggested that, for households using a water source outside the premises, the lower volume collected has an adverse impact on hygiene (although this was not quantified).

Elliott et al. (2019) noted widespread use of multiple water sources for laundry and/or bathing in low-income settings. Certain sources or source types were used for consumption and food-associated purposes, and different sources or source types were used for these other hygiene-associated purposes. From three towns in Uganda, Howard et al. (2002) reported that multiple source use was common in urban areas; however, use of water was differentiated by source or source type in only one town.

Where water is collected from a communal source, the location for laundry (at the home or at the source) may reflect cultural preferences and the nature of the settlement; greater use at the home may be expected in urban areas. For instance, in Uganda, a significant proportion of households in urban areas carried water to the home for washing clothes (Howard et al., 2002). In some communities, it may be socially acceptable for people to bathe and launder clothes at or close to a water source (Hoque et al., 1989; Gazzinelli et al., 1998; Kloos, Gazzinelli & Oliveira, 2001; Katsi et al., 2007; Barbir & Ferret, 2011). Designs for water supplies sometimes include facilities for bathing and laundry (Noda et al., 1997; Trigg, 2000).

In some communities, users of communal water sources use different sources for consumption and cooking, and for laundry and/or bathing. This may depend on judgements about the acceptability of the source for a given use (Kloos et al., 2001; Barbir & Ferret, 2011). Thompson, Porras & Tumwine (2001) reported that, in east Africa, 30% of the population without household connections to a piped water supply used unprotected water sources for laundry. This may constitute a risk to health – for instance, by increasing exposure to faecally contaminated water, water-based diseases such as schistosomiasis, and potentially other vector-borne diseases (Kloos, Gazzinelli & Oliveira, 2001). Facilities provided to reduce exposure to schistosomiasis have been associated with dramatically decreased incidence of infection (Kosinski et al., 2011, 2012). Where water is scarce or distant, the frequency of bathing and laundering may decrease, potentially increasing the risks of some infectious diseases (Thompson, Porras & Tumwine, 2001).

5.3. Reliability and continuity of water supplies

The reliability and continuity of off-premises and on-premises water sources have implications for users. In rural sub-Saharan Africa, some studies indicate that around 25% of handpumps are nonfunctional at a given time (Foster et al., 2019). In south Asia, 10–23% of water supplies are estimated as nonfunctional at a given time (Burr et al., 2015). Even when systems are functional, other deficiencies may limit the availability of water at collection points. Fisher et al. (2015) suggested that nonfunctionality is closely related to the relative rates of breakdown and repair events in rural settings. In rural Zimbabwe, Katsi et al. (2007) observed that the number of borehole pump strokes to collect water ranged from 2 to 100. Where many strokes were required, study participants reported that they grew weary and fetched less water per trip (Katsi et al., 2007).

Where water is collected from sources located off-premises, unpredictable breakdowns can lead to households spending more time and travelling greater distances to use an alternative source to obtain water. Although predictable discontinuity may cause hardship, it allows households to develop coping strategies. The greatest problems are experienced when discontinuity is frequent and unpredictable. Anecdotal evidence from African and Indian cities indicates that this is common and leads to collection of water from piped networks at odd hours, including late at night, with associated risks (e.g. impact on sleep).

Discontinuous on-plot water supplies – that is, where water is not available throughout the day, every day – substantially affect household water use. The Drawers of Water II study compared the five major factors affecting connected households' per capita daily water use between the original study and the repeat study. Per capita water use was positively correlated with hours of service for households with piped supply (Thompson, Porras & Tumwine, 2001). A little over half of households with piped connections experienced 24-hour service in Drawers of Water II, compared with almost all piped households in the original study. Between the two studies, per capita water use decreased for connected households in urban areas. The authors speculated that deteriorating infrastructure, and lack of proper operation and maintenance led to poorer service delivery. In a study of four towns in India, Andey & Kelkar (2009) found that per capita water use was higher with continuous water supplies than with intermittent water supplies. However, where there were shorter periods of supply interruption and improved household water storage, the difference in the amount of water used compared with continuous water supply was small (Andey & Kelkar, 2009).

A study in rural China compared households' per capita water use between three different water supply schemes: continuous piped supply to households, intermittent piped supply to households, and households that used public taps (Fan et al., 2013). Households with intermittent supply had comparable water use patterns and volumes (52 L/person/day) to households using public taps (46 L/person/day), and both types used less water than households with continuous supplies (71 L/person/day) (Fan et al., 2013). The amount of water used for bathing and laundry was significantly less in households with intermittent supplies and using public taps than in continuously supplied households. The practice of sharing water between household members for washing hands, feet and face was significantly more frequent in households with intermittent supplies and those using public taps than in continuously supplied households. These findings indicate that households with intermittent supplies benefited less from on-plot water supplies.

Fan et al. (2014) found that households experiencing intermittent supply first reduced their outdoor water use (for vegetable gardening and yard cleaning). With further decreases in hours of service, households reduced their water use for indoor activities. Restricting service from continuous to 6 hours/day significantly reduced household water use for outdoor activities and lowered the frequency of personal hygiene activities such as face, hand and foot washing. When water was available for 3 or fewer hours per day, per capita water use for laundry, showering and other personal hygiene was also significantly lower. A significant further reduction in overall per capita water use was observed when water was available for 1.5 or fewer hours per day compared with water being available for 6 hours per day (Fan et al., 2014). However, the amount of water used for cooking, food hygiene and washing of utensils was relatively unaffected by the number of hours of service. Households stored water to cope with intermittent supplies.

Intermittent piped service can occur as a result of system deficiencies, insufficient supply or rationing. In some urban areas, a high proportion of the population may have less than 12 hours of water service per day (Rosenberg, Talozi & Lund, 2008). To cope with intermittent supplies, households may collect water from alternative sources, purchase water from vendors, build alternative sources and/or store water (Adekalu, Osunbitan & Ojo, 2002; Pattanayak et al., 2005; Katuwal & Bohara, 2011). Increased household storage capacity was estimated to increase monthly per capita consumption by 13% in a study of households with piped connections in Sri Lanka (Nauges & van den Berg, 2009). Although these mechanisms augment supply, they increase costs to the household (Pattanayak et al., 2005). Households with intermittent piped supplies may be unwilling to pay for improvements to the piped system because they do not trust utility management to improve service delivery (Kibassa, 2011).

Qualitative evidence from India describes the effect of intermittent water supplies on outcomes such as employment and education. Focus group members reported that poor reliability of water services resulted in people missing work and/or school to fetch water, and reduced the frequency of domestic activities such as bathing, laundry and house cleaning (Subbaraman et al., 2015).

5.4. Household size and composition

Although larger households use more water (Reddy, 1999), per capita water use decreases as household size increases, because an additional person has little effect on the overall household quantity used for domestic activities such as dishwashing, house cleaning and laundry. A study of rural households in Uganda using non-piped water located off-premises found a 0.65 L decrease in per capita quantity for each additional household member (Sugita, 2006). Numerous field studies have reported an inverse relationship between household size and per capita water use (Feachem et al., 1983; Hoque et al., 1989; Blum et al., 1990; Sandiford et al., 1990; Cairncross & Kinnear, 1992; Noda et al., 1997; Thompson, Porras & Tumwine, 2001; Hadjer, Klein & Schopp, 2005; Keshavarzi et al., 2006; Arouna & Dabbert, 2010; Fan et al., 2013; Nnaji, Eluwa & Nwoji, 2013). Household size is decreasing globally, and the number of households is increasing in nearly all countries (Bartram, Elliott & Chuang, 2012). This is likely to have a net effect of increasing water demand as the increase in water required by the increasing number of households greatly exceeds marginal reductions associated with decreasing household size.

Few studies have explored water use within households. The proportion of children in the household has a statistically significant negative relationship with per capita domestic water use (Thompson, Porras & Tumwine, 2001). Water diaries have been used in a few studies to examine differences in water use among household members, often examining differences in gender. However, most have small sample sizes and are in high-income settings (Lahiri-dutt & Harriden, 2008; Harriden, 2013). The emerging examples of water diaries in low- and middle-income countries (Hoque & Hope, 2018) suggest that this approach may provide insights into household water use and intra-household variations.

Given that women are often responsible for water collection and domestic chores involving water, they may use more domestic water than other members of the household. Conflict between household members has been reported over differences in water collection burden, and who decides how water is used and for what purpose (Yerian et al., 2014).

5.5. Quantity and price

Price affects the quantity of water used by households. Empirical studies of water demand indicate that water is a normal good, so, as the price for water increases, the demand decreases, and vice versa. However, studies of residential water demand in industrialized countries have found that, although price and quantity are inversely related, demand is relatively price inelastic. This means that the percentage change in water use is smaller than the corresponding percentage change in price. Meta-analyses report average own-price elasticities of demand between –0.3 and –0.6 (Espey, Espey & Shaw, 1997; Dalhuisen et al., 2003, Worthington & Hoffman, 2008; Sebri, 2014). This means that a 10% increase in the price of water results in a 3–6% reduction in water use.

Few studies have examined the relationship between price and the quantity of domestic water used in low- and middle-income countries. Nauges & Whittington (2010) highlighted challenges in understanding the relationship between price and water use in these countries. The common practice of multiple source use poses challenges in analysing the influence of price on water use because it requires consideration of both households' choice of which source(s) to use and how much water to use from each source.

Studies examining source choice have found that factors such as price, perceived quality, time or distance and reliability influence household behaviour (Briscoe, Chakraborty & Ahmad, 1981; Mu, Whittington & Briscoe, 1990; Nauges & Strand, 2007; Basani, Isham & Reilly, 2008; Cheesman, Bennett & Hung Son, 2008; Nauges & van den Berg, 2009; Kremer et al., 2011; Coulibaly, Jakus & Keith, 2014; Gross & Elshiewy, 2019). Although only a few studies are available, they have generally found that the demand for water in low- and middle-income countries is relatively inelastic (own-price elasticities of demand between –0.1 and –0.8; Table 10).

Studies that report own-price elasticities of demand for different source types typically report aggregate values for generic source types (Table 10) – Wagner, Cook & Kimuyu (2019) is the only study that estimates source-specific own-price elasticities. For example, Nauges & Strand (2007) reported own-price elasticities of demand of –0.58 for private connections, –0.66 for public taps and –0.41 for tanker water in cities in El Salvador. Strand & Walker (2005) reported own-price elasticities of demand of –0.3 for households with a private connection and –0.1 for households without a private connection in 17 cities in Central America. In Viet Nam, Cheesman, Bennett & Hung Son (2008) found that demand was more price elastic for households with a private connection and a well (–0.53) than for those that only had a private connection (–0.06).

Less than one third of the studies (four) summarized in Table 10 estimated the demand for water in rural areas. These studies generally found that the own-price elasticities were similar for different sources. For example, in rural Benin, Gross & Elshiewy (2019) found that the own-price elasticities of demand were approximately –0.1 for public taps, public wells equipped with hand or foot pumps, and protected wells. In rural Kenya, Wagner, Cook & Kimuyu (2019) found that the own-price elasticities of demand for public taps, public wells and vended water were approximately –0.50.

Overall evidence suggests that the price of water affects both the choice of water source and the quantity of water used. The impact of price on water use and source selection depends on the magnitude of changes (or differences) in price, and may vary with households' water use, income and other factors.

It is often assumed that income and water use are highly correlated. However, there is little empirical evidence to support this assumption in low- and middle-income countries. Less than half of the studies in Table 10 estimate the income elasticity of demand. Those that do suggest that water use

Table 10. Price and income elasticities of demand in low- and middle-income countries

Study	Location	Rural/urban	Source type	Price elasticity of demand	Income elasticity of demand
Gross & Elshiewy (2019)	200 villages in Benin	Rural	Public taps	−0.11	NA
			Public wells (with hand/foot pumps)	−0.1	NA
			Protected wells	−0.1	NA
Wagner, Cook & Kimuyu (2019)	Meru county, Kenya	Rural	Public taps	−0.5	NA
			Public wells	−0.47	NA
			Vended water	−0.5	NA
Coulibaly, Jakus & Keith (2014)	Zarqa, Jordan	Urban	Private connection	−1.33	NA
			Tanker water	−2.9	NA
			Vended (treated) water	−1.43	NA
			Bottled water	−0.62	NA
Arouna & Dabbert (2010)	27 villages in Benin	Rural	Improved sources	−0.15	NA
Diakité, Semenov & Thomas (2009)	156 municipalities in Côte d'Ivoire	Urban	Private connection	−0.82	0.15
Nauges & van den Berg (2009)	Sri Lanka	Urban	Private connection	−0.15	0.14
			Private connection + public sources	−0.37	0.2
Basani, Isham & Reilly (2008)	7 towns in Cambodia	Urban	Private connection	−0.4 to −0.5	0.2 to 0.7
Cheesman, Bennett & Hung Son (2008)	Buon Ma Thuot, Viet Nam	Urban	Private connection	−0.06	0.14
			Private connection + well	−0.53	NA
Nauges & Strand (2007)	3 cities in El Salvador	Urban	Private connection	−0.58	0.2 to 0.3
			Public taps	−0.66	NA
			Tanker water	−0.41	NA
Gulyani, Talukdar & Kariuki (2005)	3 towns in Kenya	Urban	All (aggregate) sources	−0.10 to −0.16	NA
Strand & Walker (2005)	17 cities in Central America	Urban	Private connection	−0.3	<0.1
			Non-tap households	−0.1	<0.1
Acharya & Barbier (2002)	4 villages in Nigeria	Rural	Non-tap source (collect and vended)	−0.073	NA
			Vended water	−0.067	NA
Rietveld, Rouwendal & Zwart (2000)	Salatiga, Indonesia	Urban	Private connection	−1.2	0.05
David & Inocencio (1998)	Manila, Philippines	Urban	Vended water	−2.1	0.3
Crane (1994)	Jakarta, Indonesia	Urban	Vended water	−0.48	NA
			Hydrant water	−0.6	NA
Rizaiza (1991)	4 cities in Saudi Arabia	Urban	Private connection	−0.78	0.09 to 0.20
			Tanker water	−0.4	NA

NA: not available.
Source: Modified and expanded from Nauges & Whittington (2010).

is relatively income inelastic, with income elasticities of demand between 0.1 and 0.3. This means that a 10% increase in income would result in a 1% or 3% change in water use, respectively.

Several studies have found that the correlation between income and water use is quite low. For example, Fuente at al. (2016) reported a correlation coefficient of 0.15 for water use and income in Nairobi, Kenya. Similarly, Nauges & van den Berg (2009) reported a correlation coefficient of 0.22 for income and water use in three cities in Sri Lanka, and Briand et al. (2010) reported a correlation coefficient of 0.23 for income and water use in Dakar, Senegal.

This may seem counterintuitive. In urban areas, however, low-income households often have larger household sizes and are more likely to share sources with neighbours. Moreover, these studies examined the relationship between income and water use among households using similar sources (e.g. private connections) and did not capture the differences in water use between households using different source types. Households with a reliable private connection generally use more water and are wealthier than households collecting water from outside the home.

Less is known about the relationship between income and water use in rural areas. Income in rural areas is often seasonal (e.g. from sale of crops) and may be irregular. Furthermore, water may not need to be purchased regularly, so that financial contributions to water supply may be equally irregular. Thus, the relationship between income and water use in rural areas is more complex than in urban areas. This is an important area for research, given increased global attention on equity and affordability.

5.6. Seasonality

Domestic water use may be affected by season. In a study in rural Ethiopia, the quantity of water collected varied substantially by season as water sources dried up in dry seasons (Tucker et al., 2014). Although quantities used for drinking and cooking were similar in wet and dry seasons, quantities used for hygiene were lower in the dry season (Tucker et al., 2014). Elliott et al. (2017) described similar variation in use of different water sources by season in Pacific island states; use was influenced by the relative availability of alternative sources.

Where households collect rainwater, per capita water use often increases in the wet season, when water is low cost and readily accessible on-plot (Frankel & Shouvanavirakul, 1973). Households with piped water may reduce their consumption of piped water in the rainy season to lower their water bills by collecting rainwater. Hadjer, Klein & Schopp (2005) observed that water availability decreased during the dry season in Benin, resulting in households travelling further to obtain water and reduced per capita water use.

6. Household access and quantity requirements

6.1. Needs for domestic purposes

Domestic water use is affected by accessibility, continuity, reliability and price (Kayser et al., 2013). The relationships between these factors are complex. Table 11 provides guidance on likely household use based on accessibility. Where water supplies are not continuous and reliable, households will likely use less water than shown, particularly if they have inadequate coping strategies such as storage. Estimates of distance and time are based on people collecting water on foot; the use of transportation systems may change the amount of water that can be collected when the water is off-plot. The estimated quantities of water at each access level may be less where water prices exceed affordability. Recommendations on financial structures relating to water service delivery are outside the scope of this publication.

In Table 11, the amount of water required for drinking is estimated to be 5.3 L/person/day, which should be sufficient to meet the needs of lactating women undertaking moderate physical activities in warm temperatures, based on the analysis presented in section 3.4. As indicated in sections 3.6 and 4.3, there is insufficient evidence to calculate a minimum quantity of water necessary for cooking, personal hygiene and food hygiene, from empirical data. Furthermore, the evidence that does exist indicates that there is substantial variability in the water used depending on climate, cultural contexts and foods cooked; therefore, deriving a single recommended minimum is neither practical nor useful. Experience and expert opinion suggest that, under most circumstances, 20 L/person/day, corresponding to basic access, is likely to be sufficient for food hygiene, handwashing and face washing, in addition to drinking and cooking, but not other hygiene practices. This is not, however, an empirically proven volume of water; there are numerous examples of situations where poor hand, face and food hygiene is found despite these levels of service.

As noted in section 4.3, 20 L/person/day will not be sufficient in circumstances, such as disease outbreaks, demanding enhanced hygiene behaviours (including an increased frequency of handwashing) and where fomites are of concern in relation to disease transmission. In such circumstances, running water is required to support effective handwashing. This will be most effective where faucets are equipped with systems that reduce or eliminate touch, such as motion sensors or handles that may be moved using the elbow to turn water on and off, or other touchless methods. Where such technologies do not exist, there may be a need for increased cleaning of tap handles using disinfectant. In most cases, such running water will come from utility- or community-managed piped water supplies, but in some cases may be household supplies where piping of water from a point source, such as a tubewell, is available. An intermediate level of access will not in all cases provide sufficient water to support enhanced handwashing, or doing so may compromise other uses of water.

Table 11. Summary of water access, adequacy and level of health concern

Access level and typical volumes of water used in the home[a]	Accessibility of water supply	Adequacy for health needs	Level of health concern[b]
Inadequate access (quantity collected can be below 5.3 L/person/day)	More than 1000 m in distance or 30 minutes total collection time	Drinking – cannot be assured Cooking – cannot be assured Hygiene – cannot be assured at the home,[c] compromising food hygiene, handwashing and face washing; other hygiene activities have to be undertaken away from the home	Very high
Basic access[d] (average quantity unlikely to exceed 20 L/person/day)	100–1000 m in distance or 5–30 minutes total collection time	Drinking – should be assured Cooking – should be assured Hygiene – food hygiene, handwashing and face washing may be assured; bathing and laundry cannot be assured at the home but may be carried out at water source	High
Intermediate access (average quantity about 50 L/person/day)	Water delivered through one tap on- plot, or within 100 m or 5 minutes total collection time	Drinking – assured Cooking – assured Hygiene – all food hygiene, handwashing and face washing assured under non-outbreak conditions; enhanced hygiene during infectious disease outbreaks not assured; bathing and laundry at the home should also be assured	Medium
Optimal access (average quantity more than 100 L/person/day[e])	Water supplied through multiple taps and continuously available	Drinking – all needs met Cooking – all needs should be met Hygiene – all food hygiene, handwashing and face washing needs should be met, including for bathing and laundry at the home, and household cleaning	Low

[a] Quantities used are likely to be lower if the primary water source is not continuous or reliable, or if water is unaffordable.
[b] Water safety is not included in this definition. Water safety is a health concern independent of water access and use.
[c] Where alcohol-based gels are used, they may contribute to hand hygiene.
[d] For the purposes of international monitoring, the Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) defines a "basic drinking water service" as use of an "improved drinking water source" with a total collection time of 30 minutes or less (round trip). A basic drinking-water service as defined by JMP approaches, but is not the same as, "basic access" as defined in this document. The JMP defines "safely managed water" – the indicator that measures SDG Target 6.1 – as an improved water source located on-premises, available when needed, and free from faecal and priority chemical contamination" (WHO & UNICEF, 2017). This is similar to "intermediate access" as defined in this document; however, the JMP definition accepts all improved sources, including those that are not piped, whereas intermediate access here is defined in terms of access to piped water.
[e] Based on http://www.waterstatistics.org/graph/18.

The public health gains from use of more water occur in three principal increments.

- The first occurs when households acquire basic access, where the reduced distance and time involved in water collection result in quantities that should be adequate for drinking, cooking, food hygiene, handwashing and face washing, but inadequate to support bathing, laundry or household cleaning. This depends on household capacity to secure water from the off-plot source by collecting or purchasing water. These gains are compromised in circumstances demanding enhanced hygiene behaviours, such as disease outbreaks.
- Further health gains occur when piped water is reliably available on-plot, especially where running water is available (intermediate access). These arise from greater water use, with adequate quantities available for all personal and food hygiene, in addition to drinking and cooking; a decreased burden of physical collection; and associated gains in time for activities such as childcare, food preparation and productive activity (e.g. education). Intermediate access may also reduce the risk of physical attacks that have been reported during off-plot water collection. However, such levels of service may not support enhanced personal hygiene required during disease outbreaks.

- Further health gains also occur when water becomes available within the home (optimal access) as running water through multiple taps. This level of service would be sufficient to cover all drinking, cooking, food hygiene and personal hygiene. It will ensure that there are adequate water quantities for enhanced personal hygiene practices under disease outbreak conditions, providing the water supply is reliable and continuous. In addition, this level of access will permit use of water for gardening and productive purposes and so contribute to household nutrition, income and health.

Increasing levels of water access (basic, intermediate and optimal) are typically associated with improvements in water safety in terms of absence of pathogens. Water safety is important for human health and is comprehensively addressed in the *Guidelines for drinking-water quality* (WHO, 2017).

Households without basic access are unlikely to use the minimum quantity of water necessary for consumption. Ensuring that these households have reliable access to a basic water supply, and preferably intermediate access or higher, is a priority. Ensuring that everyone enjoys at least an intermediate level of access is consistent with meeting SDG Target 6.1 and should therefore be the priority for national policy in all countries.

6.2. Water accessibility, use and quantity as dimensions of water service quality and water security

Various frameworks of the multiple dimensions of water service have been developed. Water quantity and quality, source type, accessibility, reliability or continuity, equity, and price have been proposed as dimensions that should be considered in monitoring frameworks (reviewed by Kayser et al., 2013). One framework is the Household Water Insecurity Experiences scale, which covers several dimensions of access (Young et al., 2019).

The levels of access described in Table 11 can be interpreted in terms of household water security (Bradley & Bartram, 2013).

- People with inadequate access have no household water security: the quantities collected are insufficient, the effort taken to acquire water is excessive, the source may not be reliable, and safety of water cannot be assured.
- People with basic access have basic household water security, provided that water is available every day, and that quality can be assured at source and protected during subsequent handling and storage. Households with basic access may increase their household security by relying on other sources.
- People with intermediate access have household water security: sufficient water should be available for all personal domestic needs, and safety can be more readily assured if the supply is available for several hours during normal waking hours and preferably 24 hours a day. For households with intermittent supply, the level of water security may be improved through coping mechanisms such as increased storage or alternative sources, although these could have financial and health implications.
- People with optimal access are fully water secure: quantity and continuity of water are likely to be adequate for domestic water needs, provided that quality is assured, current services are sustainable, and future growth in demand and threats from climate change can be managed.

Quality is likely more readily assured for both intermediate and optimal access, but depends on continuity of supply, risk management practices of the service provider, whether household storage is needed, and the adequacy of storage and handling practices.

6.3. Household productive uses of domestic water

Productive uses of domestic water by households include brewing, small-scale food production, animal watering and household construction. They are distinct from enterprises that use water resources in income-generating activities, such as irrigation (beyond simple use of water by a household for gardening), industry, larger commercial entities, energy production and transport. In terms of overall use of water resources, economic uses of water typically greatly exceed use for domestic supply. These uses can compromise domestic uses of water through overconsumption or contamination of the water supply.

Oversight of domestic water supply by the health sector has not normally considered productive uses of water. However, these uses are valuable for low-income households and communities, and can benefit health and well-being (Thompson, Porras & Tumwine, 2001; Koppen et al., 2006; Renwick, Moriarty & Butterworth, 2007). Direct health benefits derive, for example, from improved nutrition and food security from garden crops that have been watered; in urban areas, productive uses of water are often essential for low-income communities to meet nutritional requirements. Indirect health benefits arise from increased household wealth from productive activities and reduced financial vulnerability (Renwick, Moriarty & Butterworth, 2007). Renwick, Moriarty & Butterworth (2007) estimated that each additional litre per person per day of water provided beyond 20 L generates US$ 0.50–1.00/person/year of income. Substantial increases in total household income arise from productive water-using activities (Koppen et al., 2006). Women, in particular, benefit: a study in Senegal reported that 35% of women's earned income was through work supported by water sources (Van Houweling et al., 2012).

6.4. Amenity uses of water

Amenity uses are not typically considered in relation to health aspects of water quantity. Amenity uses include lawn watering and car washing, although the latter would be a productive use if practised for income. Typically, amenity use of water increases with service level (Thompson, Porras & Tumwine, 2001). These uses provide some benefits in terms of quality of life. However, very little amenity use of water is likely for people with the least access.

The principal concern in relation to amenity uses of domestic water supplies is to reduce excessive demands that compromise access to water for consumption, hygiene and productive use. This may occur during steady state supply or at times of water scarcity. Overuse of water supplies for amenity uses occurs in low-, middle- and high-income countries. In urban areas of low- and middle-income countries, patterns of use among the wealthy have been reported to reduce the availability of water to the poor (Stephens, 1996). In some cases, restrictions are applied to conserve water resources, especially in response to unusual or seasonal scarcity.

7. Implications

The evidence reviewed and conclusions drawn here have substantive implications for the development and application of norms for water access and quantity. Investments in water supply are needed to:

- reduce the burden of water collection by bringing water points onto the household premises, which aligns with SDG Target 6.1;
- monitor and evaluate progress in meeting international and national goals for water supply;
- prioritize interventions and applications in specific contexts, such as emergencies;
- better support the response to, and preparedness for, outbreaks of both diarrhoeal and respiratory disease.

7.1. Changing the nature of the debate: accessibility versus availability

The quantity of water that households collect and use is mainly determined by accessibility – in terms of collection distance and time – followed by continuity, reliability and price of the water supply. Therefore, the debate regarding quantity is principally about the effort required to collect water from its source (i.e. accessibility), rather than the volume of water available at the source (i.e. availability, which is affected by reliability and continuity). Quantities of water used within the home can be increased by improving the accessibility of water supplies and thereby household water security, which contributes to reducing poverty.

Climate change may increasingly affect accessibility of water supplies by affecting the volume of water supplied from individual sources. It may also cause damage to infrastructure that, at least temporarily, reduces volumes of water supplied and increases interruptions to supply (Howard et al., 2016).

Where access is basic, the amount of water collected by households is likely to be no more than 20 L/person/day, and in some cases substantially less.

Intermediate access to water supplies – that is, delivery of water through an on-plot tap – should result in the use of approximately 50 L/person/day, and substantive reductions in collection effort and associated risks, although this will be influenced by reliability and continuity of supply. Intermediate access is similar but not identical to Target 6.1 of the SDGs; the latter can also be satisfied through use of non-piped water sources on-premises. Intermediate access will increase sullage and wastewater, and require adequately designed disposal systems.

Optimal access will result in much higher quantities of water being used and provides additional health gains as enhanced personal hygiene during disease outbreaks can be assured. Policy emphasis may expand to include discouraging excessive use. Once piped water becomes available within the home, wastewater flows will increase, requiring adequate wastewater and sullage management.

In many low- and middle-income countries, water system management should be improved to reduce supply interruptions. Policies and programmes should ensure water affordability for poor households, including the use of targeted subsidies. Policies should also include incentives for users to obtain a legal connection and to pay for water services (World Bank, 1993; Howard, 2001; Andres et al., 2019; Cook, Fuente & Whittington, 2020; Cook et al., 2020). Improving service delivery to the urban poor and rural communities is likely to require a range of technical options, more effective management arrangements and more effective financing (World Bank, 1993; Cotton & Tayler, 1994; Briscoe, 1996; Subramanian, Jagganathan & Meizen-Dick, 1997; Hutton & Varughese, 2016; Neto, 2016; Adams, Sambu & Smiley, 2019).

7.2. International development targets

In 2015, the United Nations General Assembly adopted the SDGs (UNGA, 2015), which include a goal on water and sanitation (SDG 6). Target 6.1 is to ensure universal access to water by 2030. The indicator to measure progress towards SDG Target 6.1 is the proportion of the population with safely managed water supplies, defined as an improved water source located on-premises, available when needed, and free from faecal and priority chemical contamination (UNGA, 2017). This level of service can be achieved with the intermediate or optimal levels of access (as defined in this document) if piped water is provided, and if the additional criteria of availability and quality are met.

The progression from basic access to intermediate access (as defined in this document) and aiming for the target of universal access are important shifts. The implications are substantial – the public health gains will likely be dramatic, provided that supplies are continuous and reliable, and water safety is assured.

SDG 6 and the recognition by the United Nations General Assembly of the human right to water (UNGA, 2010a, b) have increased the focus on equity in access to water. The recognition of the human right to water places a duty to progressively realize, using the maximum of available resources, universal access to sufficient, safe, acceptable, physically accessible and affordable water (UNGA, 2010a, b). General Comment 15 of the United Nations Committee on Economic, Social and Cultural Rights characterized the normative dimensions of availability, quality, accessibility and non-discrimination/ equity. Availability means that the amount of water available per person should correspond to the WHO recommendations as described in this publication (UN, 2003).

Realizing SDG Target 6.1 and the human right to water will require substantive investment. In 2017, 75% of the global population (5.7 billion people) had a water supply located at their homes (UNICEF & WHO, 2019). The remaining 25% of the global population (almost 2 billion people) includes more than 200 million people who need more than 30 minutes to collect drinking-water. Most people using water supplies located off their premises are in rural areas; sub-Saharan Africa is the region with the highest number of these people. Particular emphasis is needed on improving access levels in rural and peri-urban areas; among disadvantaged groups; and in sub-Saharan Africa, Southern Asia, South-Eastern Asia and Oceania.

In expanding coverage so that running water is available on-plot, three complementary activities will be needed.

- Investment will be required to ensure that such supplies can deliver a safe and reliable service to users at an affordable price. Safety and reliability are essential if the public health benefits are to be realized.
- Investments will be required to ensure that services can be sustained, including in light of current climate variability and likely future changes in climate (Howard et al., 2010, 2016). Managing these effectively will require investments to reduce vulnerability and improve preventive risk management.
- Action will be required to manage (constrain to sustainable levels) water consumption to ensure sustainable supplies for all.

In many urban and some rural areas, it should be possible to move from inadequate access to intermediate access without passing through basic access. The report by UNICEF & WHO (2019) indicates that this is happening in some countries. Responding to local conditions and opportunities will be more effective than developing blueprints for upgrading access levels. Achieving optimal or intermediate access may create problems that will need to be addressed to protect public health – notably, accumulation of wastewater and sullage, which will require improvements in wastewater management and drainage. Poorly drained water increases the risk of insect vector–borne diseases and may increase exposure to pathogens, particularly for small children who may play near or in water. It could also increase the risk of schistosomiasis. Managing these risks will require investments in drainage and sanitation to ensure safe disposal and treatment of wastes.

7.3. Emergencies and disasters

In emergencies and disasters, sufficient safe water helps to control the spread of infectious disease and prevent outbreaks of disease. The provision of sufficient safe water for drinking, cooking, food hygiene and personal hygiene should never be compromised.

According to Sphere standards, in humanitarian responses, a minimum volume of water for water intake, cooking and basic hygiene is 15 L/person/day (Sphere Project, 2018). In the acute phase of a drought, 7.5 L/person/day may be appropriate for a short time. However, this is an absolute minimum and is insufficient to ensure basic personal hygiene. In terms of estimating source volume requirements, provision of communal facilities will typically result in use of 20 L/person/day. If taps are provided to individual dwellings, this will increase to 50 L/person/day.

7.4. Quantity in water supply surveillance programmes

The health sector should advocate for interventions that will deliver the greatest improvements in health most efficiently. A key component of this role is the surveillance of water supplies to assess progress in meeting requirements specified in drinking-water regulations and to identify priority areas for intervention. WHO (1976) defines water supply surveillance as “the continuous and vigilant public health assessment and review of the safety and acceptability of drinking-water supplies”. This definition continues to be the basis for actions on surveillance as part of water safety programmes (WHO, 2017).

Water quantity has often been viewed as an indicator for surveillance programmes (Kayser et al., 2013), alongside measures of quality, price, continuity and coverage (Lloyd & Bartram, 1991; Lloyd & Helmer, 1991; WHO, 1997; Howard & Bartram, 2005). Elsewhere, it has been suggested that access level may be a more appropriate indicator (Bartram, 1999). Improving access results in more water being used by households, and thereby improved health outcomes. Data on water quantity are difficult to collect at a household level, particularly when multiple sources of water are used. Measuring the access level of households is a more feasible and meaningful indicator in many circumstances. Data on access level are easily obtainable using household surveys, and GPS coordinates of households and water sources.

Evidence about the effects of reliability and price of water supply on quantities of water used would be useful for policy development and programme implementation. This information might be obtained through a surveillance programme and would not require frequent monitoring (Lloyd & Bartram, 1991; Howard & Bartram, 2005). There appears to be little justification for collecting such data in relation to distance – since quantity is determined by accessibility, the levels of access identified in Table 11 would be sufficient.

7.5. Quality of evidence and future research needs

Overall, the quality of evidence reviewed in this document is moderate.

The quality of evidence underpinning the definition of levels of access is robust, because a consistent body of evidence points to thresholds in access that are associated with significant changes in quantities of water used. Further research into the influence of reliability and cost on water quantities used by households would improve our knowledge of the importance of these relationships. However, it is unlikely that such research will fundamentally change understanding of the points at which major shifts occur in water quantities used.

The quality of evidence underpinning recommended minimum volumes of water for drinking is moderate, because it is based on established published reference values and published literature. However, information on the water needs of people engaged in moderate activity at higher temperatures is drawn from studies of the military; translating this into the needs for civilians engaged in manual labour at higher temperatures is not straightforward. Furthermore, the minimum amount of water required is likely to vary with climate, activity, gender and life stage. This suggests that further evidence is required about water quantities to inform hydration curves for civilian populations in low- and middle-income countries. Such research may lead to changes in estimated water needs.

Insufficient evidence is available to derive a minimum quantity of water for cooking. Published food pyramids have limited use in calculating water needs because of a lack of evidence about recommended dietary requirements for low- and middle-income countries. Nutritional needs in these countries may be very different from food pyramids established for populations in high-income countries because of differences in activity levels, climate and cultural preferences. Further research is therefore required to estimate the water required for cooking for populations of low- and middle-income countries. It is not possible to define an evidence-based empirical recommendation for the quantity of water required for food hygiene. This is a gap where further research would be useful, which may change the estimate of water required.

It is difficult to draw a firm conclusion on the quality of evidence for volumes of water required for handwashing and face washing. There appears to be consistent expert opinion that provision of 20 L/person/day often allows handwashing and face washing, in addition to drinking, cooking and food hygiene. It is unlikely that further research would significantly change this conclusion, suggesting that the quality of evidence is at least moderate. At the same time, there is very little empirical data on the volumes of water required for handwashing and face washing that could inform the definition of a minimum quantity. Further research is required to understand the role of water quantity in relation to other factors that determine hygiene behaviour and hygiene-determined health outcomes. This is particularly important in situations where the demand for water for effective and more frequent handwashing – for instance, in outbreaks of disease – increases.

There are evidence gaps where further research would improve the evidence base.

- Limited high-quality evidence is available on the quantities of water used by households and for what purposes, especially where households use multiple water sources or have intermittent water supplies.
- Improving the evidence for how much water is required for effective personal hygiene would be invaluable in setting targets for minimum water.
- Further research is needed on the relationships between water quantity used by households and the factors that may influence this quantity, including accessibility, availability, reliability and cost.
- Further research is also needed on use of water outside the household to meet household needs, and on non-household use of domestic water supplies, such as in health facilities, schools, workplaces and marketplaces.

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