

# Is water carriage associated with the water carrier's health? A systematic review of quantitative and qualitative evidence

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## ABSTRACT

**Introduction** The work of carrying water falls mainly on women and children, particularly in sub-Saharan Africa and rural areas. While concerns have been raised, how water carriage is associated with health of the water carrier is not clear. The aim of this review is to summarise evidence on whether, and how, water carriage is associated with the water carrier's health.

**Methods** A systematic review of literature was conducted, searching Embase; Medline; Web of Science Social Sciences Citation Index; Web of Science Arts and Humanities Citation Index; International Initiative for Impact Evaluation website; WHO Virtual Health Sciences Library and WHO African index medicus, from inception to 8 November 2017.

**Results** Forty-two studies were included. Their ability to demonstrate cause and effect relationships was limited by study design and fair or poor methodological quality. Overall, the studies suggest that water carriage is associated with negative aspects of the water carriers' health. There is moderate quantitative and strong qualitative evidence that water carriage is associated with pain, fatigue, perinatal health problems and violence against vulnerable people, and inconclusive evidence of an association with stress or self-reported mental health and general health status.

**Conclusion** In many circumstances, water carriage is a potential barrier to Sustainable Development Goal (SDG) 6 target 'universal and equitable access to safe and affordable drinking water for all' and SDG 3 'ensure healthy lives and promote well-being for all at all ages'. Efforts should focus on providing water on premises, and where this is not possible, providing water close to home and reducing risk of gender-based violence.

## INTRODUCTION

Historically, the focus of water and health research has been on management of water quality and risk or prevalence of infectious disease. However, health is defined more broadly as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'.<sup>1</sup> More recently, interest in the work of carrying water

## Key questions

### What is already known?

- Water carriage work falls mainly on women and children, particularly in sub-Saharan Africa and rural areas.
- Water is often carried in addition to other loads, and it may not be the heaviest or key portage task leading to health issues.

### What are the new findings?

- Moderate quantitative and strong qualitative evidence indicates that water carriage is associated with pain, fatigue, perinatal health problems and violence against vulnerable people, while the evidence that water carriage is associated with stress and general health is inconclusive.

### What do the new findings imply?

- Efforts to improve access to safe drinking water should focus on achieving 'safely managed' water on premises.
- Where water fetching must continue, strategies to reduce risk of harm should focus on providing water close to home and reducing risk of gender-based violence.

from sources located away from the home, or 'off-plot', has been raised by WHO, Unicef<sup>2,3</sup> and the International Labour Organisation.<sup>4</sup> Understanding how water carriage is associated with health is relevant to the United Nations Sustainable Development Goal (SDG) 6, target 1 'universal and equitable access to safe and affordable drinking water for all',<sup>5</sup> and SDG 3, which aims to ensure 'healthy lives and promote well-being for all at all ages'.<sup>6</sup> Adverse health impacts of water carriage are likely to have implications for SDGs 1 (end poverty in all its forms), 4 (quality education), 5 (gender equality), 8 (decent work and economic growth), 10 (reduced inequalities) and 16 (promote peaceful and

inclusive societies).<sup>7</sup> They would also make water access inequitable for those obtaining water off-plot compared with people with safe water piped into their homes, and directly create inequity in relation to SDG 3.

Previous research has demonstrated an association between distance or time to water source and health of children in the home, as indicated by diarrhoeal disease, and child anthropometrics and mortality.<sup>8-10</sup> Stelmach and Clasen<sup>11</sup> reviewed the association between water quantity and health. In low-income countries, incidence of trachoma and gastrointestinal-related disease improved with increased quantity of water in the home, and in high-income countries, higher levels of water consumption were associated with renal and bladder cancer, but not type II diabetes. What is absent from these studies of distance to water source and increased household water quantity, is investigation of how these factors affect the health of the person who brings water into the home. It is clear that women and children most commonly collect and carry water home for household use,<sup>3 12 13</sup> often by carrying 20–25 L containers on their head<sup>14</sup> or by other methods such as loading a number of containers into a wheelbarrow.<sup>15 16</sup> While concerns have been raised, what remains unclear, is how the work of water carriage is associated with the health of the water carrier. With more attention focused on this issue in recent years, a review of the published literature to summarise what is currently known and identify gaps in the existing knowledge base is timely. Therefore, a systematic review of published literature was conducted with the aim of answering the review question: ‘Is the work of water carriage associated with the health of individuals who fetch and carry water for household use?’

## METHODS

A systematic review of literature was undertaken to identify research investigating the relationship between water carriage and health.

### Search strategy and selection criteria

A search of electronic databases was conducted from inception to 8 November 2017 by one reviewer (JLG). Seven electronic databases were accessed: Embase; Medline; Web of Science Social Sciences Citation Index selecting public, occupational and environmental health themes; Web of Science Arts and Humanities Citation Index; grey literature databases provided by the International Initiative for Impact Evaluation (<http://www.3ieimpact.org/>), the WHO Virtual Health Sciences Library ([www.emro.who.int/information-resources/vhsl/](http://www.emro.who.int/information-resources/vhsl/)) and the WHO African index medicus. Experts in the field of water access and health were also contacted to identify relevant literature and reference lists of included papers were checked for relevant papers.

One researcher (JLG) independently exported titles and abstracts of all retrieved citations into endnote (X7) and removed duplicates. Retrieved titles and abstracts

were evaluated against predefined inclusion criteria by two reviewers (JLG and PRH). Studies were included in the review if they reported quantitatively measured variables or qualitative reports related to the work of fetching water from an off-plot or out of home source and carrying it back home *and* included some measurement or qualitative appraisal of the health of the person who performed the water carriage work. Studies were excluded if they did not present any quantitative or qualitative analysis of the relationship between water carriage and health of people who perform water carriage work.

### Inclusion criteria

- ▶ Quantitative research reporting the relationship between variables related to the physical work of carrying filled water containers *and* variables related to the health of the water carrier.
- ▶ Qualitative research where people who carry water report the effect of water carriage on their own health or the health of others who carry water.
- ▶ Studies reported in English, French, Spanish, Portuguese, Swedish or Turkish.

### Exclusion criteria

- ▶ Studies reporting health only of children aged 5 or less, because children of this age are much less likely to carry significant water for household use.
- ▶ Studies reporting variables related to water access and water carrying, but not reporting health of the water carrier other than prevalence or indicators of infectious or vectorborne diseases.
- ▶ Article with a topic focus on sanitation, hygiene, water source type and water source or household water contamination or treatment, without data on the work of water carriage and health of water carriers.
- ▶ Article with information on ‘water insecurity’ and health, without any data about the association between physically carrying water containers (as an aspect of water security) and health, disaggregated from other aspects of water insecurity (such as limited water quantity or quality).

Advanced searches were conducted using key terms combined with boolean operators to maximise search sensitivity. Terms were also mapped to medical subject headings (MeSH) in Medline and Embase. Truncation terms and searches in all fields ‘.af’ were used to maximise search sensitivity in each database where possible (online supplementary appendix 1).

### Data analysis

Summary measures, statistics and qualitative themes reported in the studies were diverse, and findings are presented as reported in each study. Where studies separately presented analyses of multiple risk factors or independent variables, and multiple outcomes or dependent variables, only findings which reported the relationship between variables related to the work of water carriage and health outcomes of the water carrier were extracted.

No studies were excluded on the basis of methodological quality, which was appraised independently by two reviewers: JLG and CH for qualitative aspects of studies, and JLG and JHG for quantitative aspects of studies. Where differences in quality scores could not be agreed, a third reviewer (PRH) was consulted to achieve consensus. The US Department of Health and Human Services, National Institutes of Health (NIH) Quality Assessment tool for observational cohort and cross-sectional studies<sup>17</sup> was used for 26 studies which reported quantitative data, and the Critical Appraisal Skills Programme (CASP) tool<sup>18</sup> was used for 21 studies which were qualitative or of mixed methods and reporting a qualitative component to the study.

Meta-analysis was planned. However, the studies included in the review were too heterogeneous to perform a meta-analysis, because of differences in the characteristics of study samples, and exposure variables or outcomes measured, therefore a narrative synthesis was completed. A wide variety of systems to grade the strength of evidence gathered in systematic reviews have been reported, however most place emphasis on a hierarchy of research design considered most robust for determining the effectiveness of a clinical intervention.<sup>19</sup> We therefore used a system reported by Hoogendoorn *et al*,<sup>20</sup> to rate the strength of evidence from observational cohort and case-referent studies, considering study quality, number and consistency of findings. We modified the approach by Hoogendoorn *et al* by applying it to the synthesis of cross-sectional and qualitative studies, and incorporating the NIH and CASP ratings of study quality, because we aimed to identify whether water carriage is associated with reported health problems, even if it were not possible to establish a cause and effect relationship. There was no funding source for this study.

## RESULTS

Nineteen thousand, seven hundred and fifty-eight titles were retrieved through the electronic database searches (figure 1). Once duplicates were removed, 12 131 articles remained for further screening of abstracts and titles against the inclusion and exclusion criteria. Of these, 11 789 articles were excluded (305 remained), because the title and abstract clearly indicated that the content was irrelevant to the purpose of this review; or because health outcomes were reported only for children aged 5 years or less or for cases of infectious disease; or they reported only sanitation and hygiene practices or household water supply type without information about water source location (ie, does not indicate need for water fetching work). A further 37 papers were flagged electronically while retrieving full-text papers from the databases, identified in reference lists of retrieved papers or obtained from contacting water, sanitation and hygiene (WASH) experts.

In total, the full text of 342 articles was obtained for review against the inclusion and exclusion criteria. Of

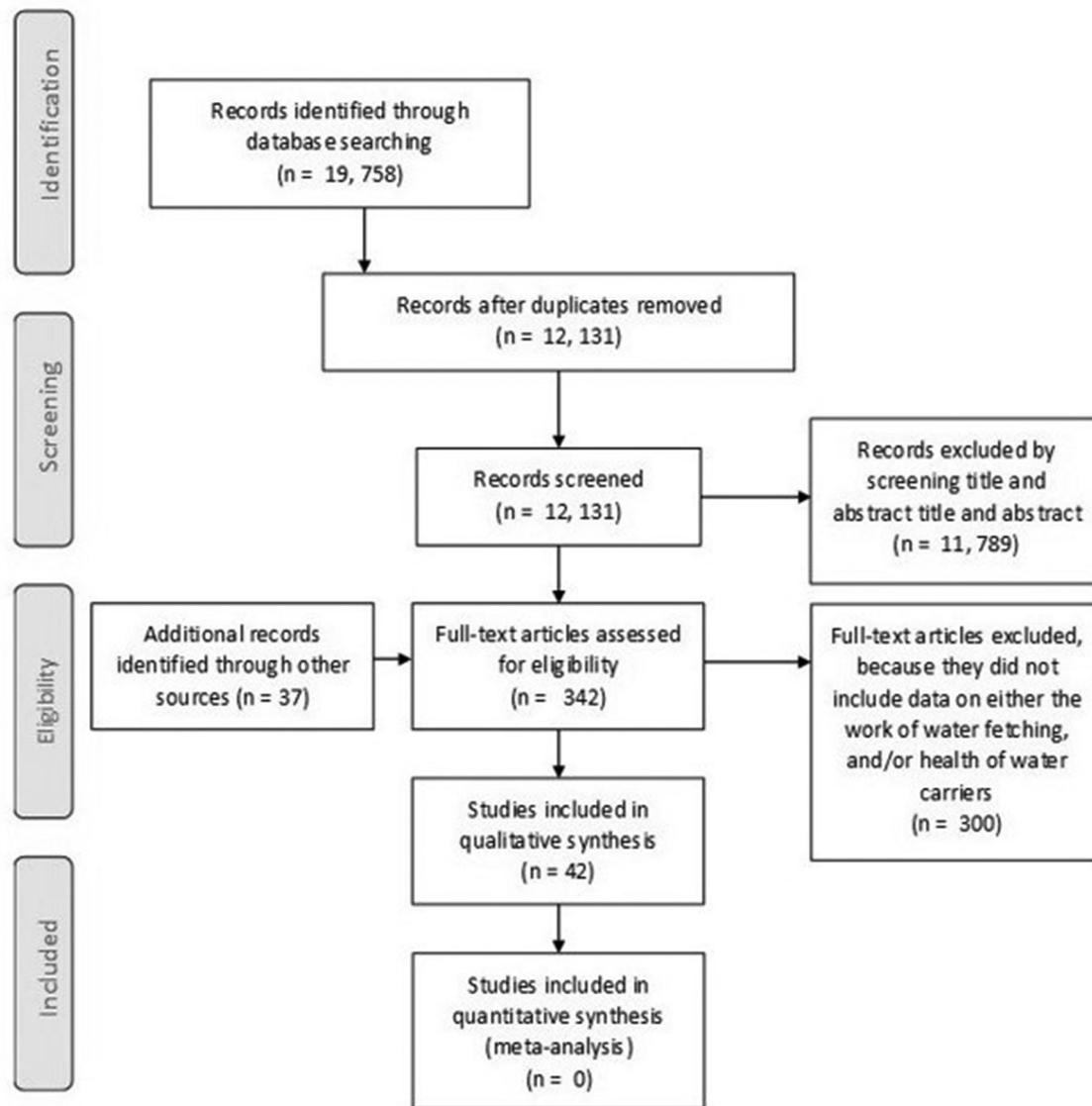
these, 300 were excluded because they did not include data on either the work of water fetching or health of water carriers or both. Articles which focused on the health impact of physical contact with water at the point of collection, for example, reporting prevalence of schistosomiasis infection and observed or reported water contact time during water fetching activities, were also excluded because such studies do not provide information on the association between health and the work of carrying water containers home. In total, 42 articles were included in the review, which reported associations with the health of water carriers and the work of water carriage.

Twenty-six studies collected quantitative data.<sup>1421–45</sup> The overall methodological quality of the studies, in terms of their capacity to demonstrate a cause and effect relationship between the work of water carriage and health was rated as fair (6 studies) or poor (19 studies), only one was rated as good (table 1). The key reasons for low-quality ratings were the use of cross-sectional study design, lack of evidence to support the reliability and validity of exposure or outcome measures, lack of outcome assessor blinding and failure to include confounding factors in analyses.

Twenty-one studies reported qualitative data.<sup>23 26 31 32 34 35 44 46–59</sup> (table 2). While almost all seemed to have appropriately chosen a qualitative research design to meet their aims and provided a clear statement of research findings, there was often insufficient information reported to determine whether recruitment, data collection and analysis were appropriate and sufficiently rigorous. The influence of the researcher and ethical issues were also not clearly reported in most of the studies. We rated studies as ‘good’ if six or more of the appraisal criteria scored a ‘yes’ response, fair if four or five criteria had yes responses and poor if three or fewer had yes responses. The scoring process resulted in 12 of the studies being rated as of good quality, 5 of fair quality and 4 rated as poor quality.

The articles reported health and social outcomes including bodily pain, energy expenditure or fatigue, stress or mental well-being, perinatal health and access to healthcare services, lack of safety or discrimination related to social vulnerability and general health status. The studies reporting social outcomes of safety and discrimination were included because of the clear and likely direct impact of the reported social factors on the water carrier’s physical or psychological health. The reported health outcomes are grouped for comparison under key themes: bodily pain, energy expenditure and fatigue, stress and mental well-being, perinatal health, social vulnerability and general health.

There is moderate evidence from quantitative data and strong evidence from qualitative data of an association between water carriage and self-reported pain or injury (tables 3 and 4). Sixteen reports of 15 studies<sup>14 26 28 29 31–33 39 43 46 47 52–54 58 59</sup> included people within their study samples whose experience of water



**Figure 1** Study selection (Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2009).

carriage was associated qualitatively, or through quantitative analysis, with pain, injury or risk of injury (table 5). The significantly reduced distance walked and time spent for water fetching among head-loading water carriers who reported pain, compared with those who did not report pain, was interpreted by Geere *et al*,<sup>14</sup> as an indication of pain-related disability. They suggested that people who experienced pain during water fetching may reduce the length of time they are exposed to the loading force, while those without pain or with lower levels of pain may be able to collect water from greater distances. Although their study was limited by a small sample size, their findings are supported by the studies including qualitative data derived from people who collect water. They are also supported by the findings of Rauniyar *et al*,<sup>29</sup> who attributed a significant 5% reduction in the 'drudgery' of water fetching among the lowest socioeconomic group to water supply projects, and the findings of Porter *et al*,<sup>60</sup> who found high proportions of children reporting pain as a direct result of load-carrying, which particularly for

girls, included water carriage by head loading. However, as highlighted by Porter *et al*,<sup>60 61</sup> individuals in low-income and middle-income countries carry diverse loads, and water may not be the heaviest load carried. Because none of the studies took this into account in their analyses, the effects of manual labour in addition to water carriage may confound the apparent associations between water carriage and pain.

In a recent study, Geere *et al*<sup>43</sup> did not find an association between pain in the previous 7 days and history of water carriage, but did find that among people reporting pain, the area of the body in which pain was experienced was associated with a history of water carriage. Ten studies<sup>14 26 28 29 31–33 43 53 58</sup> included some indication of the areas of the body in which water carriers experienced pain, with back and neck pain commonly reported. Geere *et al*<sup>43</sup> found that participants reported multiple areas of pain, and that pain areas were correlated. Principal component analysis explained 55% of the variance in pain locations and extracted two factors correlated

**Table 1** Quality appraisal cohort studies (National Institutes of Health critical appraisal tool)

First author and date (listed in chronological order)	Was the research question or objective in this paper clearly stated?	Was the study population clearly specified and defined?	Was the participation rate of eligible persons at least 50%?	Were all the subjects selected or recruited from the same or similar populations?	Was the sample size justification, power description or variance and effect estimates provided?	For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome?	Were exposure measures (independent variables) clearly defined, valid, reliable and implemented consistently across all study participants?	Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	Was loss to follow-up after baseline 20% or less?	Were the potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	Overall rating of study quality for determining cause and effect relationship
Buor 2004 <sup>21</sup>	Y	Y	N	N	N	N	N	Y	N	NR	NA	N	Poor
McCray 2004 <sup>22</sup>	N	Y	N	Y	N	N	Y	Y	CD	N	NA	Y	Fair
Foggin 2006 <sup>23</sup>	Y	Y	N	N	N	N	N	N	Y	N	NA	N	Poor
Gibson 2006 <sup>24</sup>	Y	Y	NR	N	N	Y	Y	N	Y	NR	NR	N	Fair
Rao, 2006 <sup>25</sup>	Y	Y	N	CD	N	N	Y	Y	N	N	NA	N	Poor
Hemson 2007 <sup>26</sup>	N	Y	CD	CD	N	N	Y	Y	N	N	NA	N	Poor
BeLue 2008 <sup>27</sup>	Y	Y	CD	Y	N	N	Y	Y	CD	CD	NA	N	Poor
Borah 2010 <sup>28</sup>	N	Y	NR	Y	N	N	N	N	N	N	NA	N	Poor
Geere 2010 <sup>46</sup>	Y	Y	N	Y	N	N	Y	Y	N	N	NA	N	Poor
Rauniyar 2011 <sup>29</sup>	Y	Y	N	Y	N	N	N	N	N	CD	NA	Y	Poor
Devoto 2012 <sup>30</sup>	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Good
Singh 2012 <sup>33</sup>	Y	Y	CD	N	N	N	N	N	N	CD	NA	N	Poor
Stevenson 2012 <sup>34</sup>	Y	Y	NR	Y	N	N	N	N	N	NR	NR	Y	Poor
Yallew, 2012 <sup>35</sup>	Y	Y	N	Y	N	N	Y	Y	N	N	NA	N	Poor
Asaba 2013 <sup>31</sup>	N	Y	N	Y	N	N	N	N	N	N	NA	N	Poor
Robson 2013 <sup>32</sup>	Y	Y	CD	N	Y	N	Y	Y	N	N	NA	N	Poor
Henley 2014 <sup>36</sup>	Y	Y	N	N	N	N	N	N	Y	NR	NA	Y	Fair
Mugambe 2014 <sup>37</sup>	Y	Y	N	Y	Y	N	Y	Y	N	N	NA	Y	Fair
Ono 2014 <sup>38</sup>	Y	Y	CD	Y	N	N	Y	Y	Y	N	NA	Y	Fair
Berrian 2016 <sup>39</sup>	Y	Y	Y	Y	Y	N	Y	Y	N	NR	NA	N	Poor
Cook 2016 <sup>40</sup>	Y	Y	CD	Y	N	N	Y	Y	CD	CD	NA	N	Poor
Hennegan 2016 <sup>45</sup>	Y	Y	N	Y	N	N	NA	Y	N	N	Y	N	Poor
Krumdieck 2016 <sup>41</sup>	Y	Y	Y	Y	N	N	N	N	N	NR	NA	N	Poor
Dapaah 2017 <sup>42</sup>	Y	Y	N	Y	N	N	N	N	N	N	NA	N	Poor
Geere 2018 <sup>43</sup>	Y	Y	Y	N	Y	N	Y	Y	Y	Y	NA	Y	Fair
Thomas 2018 <sup>44</sup>	Y	Y	N	Y	N	N	Y	Y	N	N	NA	Y	Poor

CD, cannot determine; N, no; NA, not applicable; NR, not reported; Y, yes.

**Table 2** Quality appraisal studies reporting qualitative data (CASP tool)

First author and date (listed in chronological, then alphabetical order)	Research design			Relationship between researcher and participants			Quality rating: Poor≤3 Fair=4–5 Good≥6
	Was there a clear statement of aims?	Is a qualitative method appropriate?	Recruitment strategy appropriate to research aims?	Data collected to address research issue?	Have ethical issues been considered?	Was the data analysis sufficiently rigorous?	
Foggin 2006 <sup>23</sup>	Yes	Yes	Cannot tell	Yes	Cannot tell	Cannot tell	Fair
Hemson 2007 <sup>26</sup>	Yes	Yes	Cannot tell	Cannot tell	Cannot tell	Cannot tell	Fair
Geere 2010 and <sup>46</sup>	Yes	Yes	Yes	Yes	Cannot tell	Cannot tell	Good
Domènech 2012 <sup>47</sup>	Yes	Yes	Cannot tell	Yes	Cannot tell	Cannot tell	Fair
Stevenson 2012 <sup>34</sup>	Yes	Yes	Yes	Yes	Yes	Yes	Good
Yallew, 2012 <sup>35</sup>	Yes	Yes	Cannot tell	Yes	Cannot tell	Cannot tell	Good
Asaba 2013 <sup>31</sup>	Yes	Yes	Yes	Cannot tell	Cannot tell	Cannot tell	Fair
Robson 2013 <sup>32</sup>	Yes	Cannot tell	Cannot tell	Cannot tell	No	Cannot tell	Poor
House 2014 <sup>48</sup>	Yes	Cannot tell	Cannot tell	Cannot tell	Cannot tell	Cannot tell	Poor
Isoko 2014 <sup>49</sup>	Yes	Yes	Yes	Yes	Cannot tell	Cannot tell	Good
Mukhulani 2014 <sup>50</sup>	Yes	Yes	Cannot tell	Cannot tell	Cannot tell	Cannot tell	Fair
Schatz 2014 <sup>51</sup>	Yes	Yes	Yes	Yes	Cannot tell	Yes	Good
Bisung 2015 <sup>52</sup>	Yes	Yes	Yes	Yes	Yes	Yes	Good
Sarkar 2015 <sup>53</sup>	Yes	Yes	Yes	Yes	Yes	Cannot tell	Good
Subbaraman 2015 <sup>54</sup>	Yes	Yes	Yes	Yes	Yes	Yes	Good
Ghosh 2016 <sup>55</sup>	Yes	Yes	Yes	Yes	Cannot tell	Yes	Good
Mbereko 2016 <sup>56</sup>	No	Yes	Cannot tell	Yes	Cannot tell	Yes	Good
Zolnikov 2016 <sup>57</sup>	Yes	Yes	Yes	Yes	Cannot tell	Yes	Good
Ayoade 2017 <sup>58</sup>	Yes	Cannot tell	Cannot tell	Yes	No	Cannot tell	Poor
Mercer 2017 <sup>59</sup>	Yes	Yes	Yes	Yes	Cannot tell	Yes	Good
Thomas 2018 <sup>44</sup>	Yes	Cannot tell	Cannot tell	Cannot tell	No	Cannot tell	Poor

**Table 3** Strength of evidence from quantitative data

Health domain	Quality*	Quantity†	Consistency‡	Strength of evidence§
Pain and injury	One fair, eight poor	9	Consistent: 100% associate WC and pain	Moderate
Fatigue and energy expenditure	One fair, six poor	7	Consistent: 100% associate WC and increased fatigue	Moderate
Stress, mental well-being or life satisfaction	One good, one fair, three poor	5	Inconsistent: 3 (60%) associate WC and increased stress; 2 (40%) found no significant effect of reduced water collection time on mental health or life satisfaction	Inconclusive
Perinatal health	Three fair	3	Consistent: 100% associate WC and reduced perinatal health or care access	Moderate
Social vulnerability	One good, one fair, five poor	7	Consistent: 100% associate WC and social vulnerability or risks	Moderate
General health	One fair, three poor	4	Inconsistent: 3 (75%) associate WC and poorer health	Inconclusive

\*Quality score based on National Institutes of Health tool, qualitative and quantitative data of mixed methods studies rated separately, such that total number of rating scores can be greater than number of studies.

†Number of studies.

‡Inconsistent: if  $\leq 75\%$  of the available studies reported the same conclusion.

§Evidence based on quality, number and the outcome of studies: strong=provided by generally consistent findings in multiple high-quality quantitative studies; moderate=generally consistent findings in one high-quality quantitative study and one low-quality study, or in multiple low-quality studies; inconclusive evidence=only one study available or inconsistent findings in multiple studies.<sup>20</sup>

WC, water carriage.

with patterns of pain distribution. The factor 'axial compression' was correlated with head, upper back, chest/rib, hands and abdomen/stomach pain. The association was proposed to indicate detrimental impacts of axial spinal loading, because participants who had previously or currently carried water had a mean increase in axial compression factor score compared with people who had never carried water, and the association was stronger among head loaders compared with those using other methods of water carriage. The factor 'soft tissue strain' was correlated with neck, upper limb pain, lower back and lower limb pain, and was slightly negatively associated with those having history of water carriage. While these findings may seem to contradict earlier data reporting complaints of neck and back pain during water carriage, the 'axial compression' pain pattern associated with water carriage was interpreted as pain referral from an underlying neck disorder.

All studies relied on self-report of pain, which is appropriate and necessary as pain is a subjective and emotional experience.<sup>62</sup> Self-reported pain intensity scales have been shown to be valid and reliable for use in clinical trials to evaluate pain severity caused by a range of medical conditions,<sup>63–65</sup> however, only one of the studies reported findings based on a pain intensity scale,<sup>33</sup> and the scale was not clearly defined in the published report. No other studies qualified participants' reports of pain in terms of

its quality, severity or effect on functioning. Qualification of pain is important because it is a common phenomenon, and can range from mild intensity which does not affect functioning or quality of life to severe pain which is disabling and/or reduces quality of life. Studies should focus on whether the work of water carriage is associated with pain which is of a quality or intensity sufficient to impair functioning or reduce quality of life.<sup>66</sup>

Seven studies included qualitative reports from participants, in which they associated physical injury with water fetching,<sup>31 32 46 47 53 58 59</sup> and four described fear of injury due to water carriage along routes or from locations frequented by dangerous animals.<sup>31 32 39 59</sup> One study reported three cases of a child drowning at open wells or ponds,<sup>31</sup> participants in another study reported fear or risk of being swept away or drowning during floods<sup>32</sup> and a further study included participants who had witnessed people struck by moving vehicles while fetching water.<sup>58</sup>

There is moderate evidence of an association between fatigue or tiredness and water carriage from quantitative data (table 3) and strong evidence from qualitative data (table 4). Five of 11 studies (12 publications) reporting tiredness, fatigue or exhaustion affecting water carriers (table 6), described associations with worsened family relationships,<sup>57</sup> poorer health status<sup>24 26</sup> and reduced engagement with education.<sup>32 58</sup> Two studies measured energy expenditure.<sup>25 28</sup> As an index of total energy

**Table 4** Strength of evidence from qualitative data

Health domain	Quality*	Quantity†	Consistency‡	Strength of evidence§
Pain and injury	Five good, two fair, two poor	9	Consistent: 100% associate WC and pain	Strong
Fatigue and energy expenditure	Three good, two fair, two poor	7	Consistent: 100% associate WC and increased fatigue	Strong
Stress	Two good, one poor	3	Inconsistent: 2 (66%) good quality studies associate WC and increased stress, one study found no effect	Strong
Perinatal health	Two good, one poor	3	Consistent: 100% associate WC and reduced perinatal health or care access	Strong
Social vulnerability	Five good, three fair, three poor	11	Consistent: 100% associate WC and worse social vulnerability	Strong
General health	Two good	2	Inconsistent: 1 (50%) associate WC and poorer health, 1 (50%) associate WC and better health	Inconclusive

\*Quality score based on CASP tool, qualitative and quantitative data of mixed methods studies rated separately, such that total number of rating scores can be greater than number of studies.

†Number of studies.

‡Inconsistent: if  $\leq 75\%$  of the available studies reported the same conclusion.

§Evidence based on quality, number and the outcome of studies: strong=provided by generally consistent findings in multiple high-quality qualitative studies; moderate=generally consistent findings in one high-quality study and one low-quality qualitative study, or in multiple low-quality studies; inconclusive evidence=only one study available or inconsistent findings in multiple studies.<sup>20</sup>

WC, water carriage.

expenditure, Rao *et al*<sup>25</sup> described drawing water as moderate physical activity, and carrying two containers on the head as heavy physical activity, while Borah *et al*<sup>28</sup> categorised drawing and carrying water home as moderately to very heavy. However, the energy expenditure measurements were done on very small samples of women in India, and may not be generalisable to other populations. Together with other studies in this review, which found that rating of perceived exertion is correlated with weight of water carried and path incline,<sup>14</sup> that energy expenditure for water carriage may be most important in food scarce regions<sup>47</sup> and that water points which reduce water fetching increase birth rates,<sup>24</sup> current evidence highlights that the energetic cost of water carriage has potentially detrimental effects on health and well-being, manifesting as tiredness or fatigue.

We found inconclusive evidence that water carriage is associated with stress from quantitative data (table 3) and strong evidence from qualitative data (table 4). Two rigorous qualitative studies,<sup>34 57</sup> and one fair quality<sup>36</sup> and two poor quality<sup>27 34</sup> cross-sectional surveys, reported water carriage to be associated with stress (table 7). In these studies, psychosocial distress was identified as an effect of water carriage by thematic analysis, and measured using three different questionnaires and by quantification of hair cortisol content as a biomarker for chronic stress. Despite the different indicators of stress, all of the

studies elucidated mechanisms by which water carriage might cause stress. These included feeling unsafe during water collection,<sup>36</sup> having insufficient time for family members to spend with each other or discuss household issues,<sup>57</sup> the physical difficulty of water carriage with a young child,<sup>27</sup> risk of physical assault or rape, extremes of temperature, queuing times and inability to complete household tasks triggering arguments between married couples.<sup>34</sup> Considering issues related to social vulnerability which are discussed below, it is plausible that water carriers experience stress related to fear of conflict or abuse.<sup>48</sup> However, one good quality cohort study failed to find any significant association with respondents' mental well-being or life satisfaction and connection to a piped water supply, among participants with above median time spent fetching water at baseline.<sup>30</sup> One mixed methods study failed to find an association between emotional distress and water fetching time, even though participants found water collection to be 'bothersome' because of having to collect water at night.<sup>44</sup> The findings of these studies are inconsistent with the others, however, they should be considered with some caution. The outcome measurement of mental well-being in the study by Devoto *et al*<sup>30</sup> was derived from a composite score and its validity and reliability for use with the study population was not reported, and while socioeconomic status was included, other potential confounding factors which might affect

**Table 5** Water carriage and pain or injury

First author and date	Population	Study type	Dates	Key findings	Quality
Hemson 2007 <sup>26</sup>	South Africa: 1052 children aged 5–17 years from 366 households, in three villages with no piped water supply	Mixed methods	NR	96% of the children reporting that their health had worsened, reported that they had a sore neck or back.	Poor* Fair†
Borah 2010 <sup>28</sup>	India: 30 rural women with normal blood pressure and temperature aged 21–40 years in Jorhat district of upper Brahmaputra Valley Zone of Assam	Observational study	NR	Incidence of pain during complete water fetching cycle, and with subactivities was mainly in low back region. Pain also reported in shoulder joints while drawing water and carrying it home.	Poor*
Geere 2010a <sup>46</sup>	South Africa: subgroup of 29 people interviewed, drawn from convenience sample of 39 adults and children fetching water in six rural villages of Limpopo Province	Mixed methodst	2008	Prevalence of spinal (neck or back pain) among water carriers was 69% and back pain alone was 38%.	Poor*
Geere 2010a and b <sup>46</sup>	South Africa: 39 adults and children observed to fetch water in six rural villages of Limpopo Province	Qualitative†	2008	Children linked water fetching to pain, spinal mobility problems and injury.	Good†
Rauniyar 2011 <sup>29</sup>	Pakistan: 1301 'treatment' households of rural water and sanitation project villages and 1301 matched comparison households in non-project villages	Cross-sectional survey	2008	A significant 5% (p<0.001) reduction in 'drudgery' defined as pain from fetching water due to muscle strain, back ache or blisters, attributed to water and sanitation projects; remained highly significant for lowest socioeconomic group in subgroup analyses.	Poor*
Domenech 2012 <sup>47</sup>	Nepal: 120 households of 10 communities (2 communities from each district) of Kaski, Syangja, Palpa, Gulmi and Doti districts	Mixed methods§	2008–2009	Rain water harvesting at the house reported to reduce 'numbers of accidents and injuries during water collection'.	Fair†
Singh 2012 <sup>33</sup>	India: 100 agricultural workers (50 male and 50 female) engaged in agricultural tasks in last 10 years, from villages of Udaipur district of Rajasthan	Cross-sectional survey	NR	Male and female respondents reported severe neck and shoulder pain during water fetching; severe lower back pain felt by female respondents during water fetching.	Poor*
Asaba 2013 <sup>31</sup>	Uganda: survey of 602 (~35%) households in Makondo Parish, and in-depth interviews, focus group discussions and participant observation in four villages	Mixed methods	2011–2012	Three cases of a child drowning at open wells or ponds reported; accidental injury due to slips and falls while water fetching and fear of animal attacks also reported; among men and women, and male and female youths and children, carrying water was perceived to cause chest pain (33.3%–64.4%); headache (5.7%–23.1%); nasal bleeding (0.8%–4.0%); back pain (0.8%–1.9%); spinal problems (0.3%–0.8%) and no problem (11.1%–32.9%).	Poor* Fair†
Robson 2013 <sup>32</sup>	Malawi: 1504 children aged 9–18 years from 12 field sites in each of 3 regions	Mixed methods	2006–2009	35% of children reported pains and health problems as their biggest difficulty in carrying water; headaches and neck aches most frequently cited (26%). Of children citing water carrying as their heaviest load, 5% more girls than boys reported bodily aches and pain in the last week. Supported by qualitative evidence from adults and children. Children (22%) reported hazards or risks of water fetching, such as rough terrain, stream/river crossings, snake or dog attacks, vehicles or risk of being swept away or drowning during floods.	Poor*† <sup>1 2</sup>
Bisung 2015 <sup>52</sup>	Kenya: convenience sample of 8 women living in Usoma, 15 km from Kisumu	Qualitative (photovoice)	2013	Photograph used to illustrate that children fetch water bare footed and are exposed to injuries.	Good†
Sarkar 2015 <sup>53</sup>	Canada: 37% of adults and 100% of high school students living in the sub-Arctic nuit community Black Tickle-Domino, located on the remote Island of Ponds, off the coast of southern Labrador	Mixed methods§	2013	Study participants attributed chronic back and shoulder injuries to carrying heavy water buckets every day. Some men required surgery, but indefinitely postponed surgery due to 'the unavailability of alternative persons to retrieve water for their families'.	Good†
Subbaraman 2015 <sup>54</sup>	India: interviews with 40 adults in Mumbai slum; 3 focus groups (FG) of 6–9 women; 3 FG of 6–9 men	Qualitative	2011	Physical strain occurs from water fetching, particularly impacting negatively the elderly, women and children.	Good†

Continued

**Table 5** Continued

First author and date	Population	Study type	Dates	Key findings	Quality
Berrian 2016 <sup>39</sup>	South Africa: 256 surveys within four purposively selected villages of Mnisi study area, Bushbuckridge Local Municipality, Mpumalanga	Cross-sectional survey	2013	224 (85%) respondents believed that shared water sources among people, livestock and wild animals could be a health risk; 118 (45%) reported household water collection from places shared with animals. 'Most' survey participants dislike wildlife around their community, perceived as a threat to personal safety.	Poor*
Ayoade 2017 <sup>58</sup>	Nigeria: 800 girls aged 5–15 years in periurban areas of Abeokuta, Ogun Stat	Qualitative	2013–2014	788 (95%) experienced neck and back pain from carrying an excessive load of water and most reported a belief that their back pains worsened during menstruation as a result of heavy water carrying; 90% have experienced some form of violence (fights or punishment) and injury (slips, stepping on nails/glass); 166 (21%) experienced injury from physical fights at water points; 345 (41%) witnessed friends or neighbours struck by moving vehicles while fetching water.	Poor†
Mercer 2017 <sup>59</sup>	Canadian subarctic: seven purposively selected households (21 people) in Black Tickle-Domino Inuit community	Mixed methods‡	NR	40.92% reduction in water retrieval time with rain water harvesting, explained by participants to mean less lifting and carrying of heavy water containers and potentially fewer injuries. Reported fear and anxiety of polar bear attack during water retrieval.	Good†
Geere 2018 <sup>43</sup>	South Africa, Ghana, Vietnam: 1 adult and 1 child from 673 households with at-house and off-plot water supply	Cross-sectional survey	2012–2013	People who previously carried water had increased risk of pain in hands (RR 3.62, 95% CI 1.34 to 9.75) and upper back (RR 2.27, 95% CI 1.17 to 4.40), as did people who currently carry water (RR hand pain 3.11, 95% CI 1.34 to 7.23; RR upper back pain 2.16, 95% CI 1.25 to 3.73) compared with people who never carried water. Mean 'axial compression' factor score (correlated with pain in head, upper back, chest/ribs, hands, feet and abdomen/stomach) associated with current (0.30, 95% CI 0.17 to 0.43) or previous (0.21, 95% CI 0.01 to 0.42) water carriage. Mean 'soft tissue strain' factor score (correlated with pain in the neck, shoulders/arms, lower back and hips/pelvis or legs), negatively associated with currently (–0.18, 95% CI –0.32 to –0.04) carrying water.	Fair*

\*Methodological quality rating of cohort study or cross-sectional survey.

†Methodological quality rating of qualitative study or reporting of qualitative findings as part of a mixed methods study.

‡Quantitative data reported by Sarkar *et al* and Doménech *et al* were water quality testing.

§No quantitative health data were collected for analysis against water retrieval time.

¶Small amount of qualitative data presented in Geere 2010a are drawn from study reported in Geere 2010b.

RR, relative risk.

**Table 6** Water carriage and energy expenditure or fatigue

First author and date	Population	Study type	Dates	Key finding	Quality
Gibson 2006 <sup>24</sup>	Ethiopia: agropastoralist community, 1548 women aged 15–49 years in a demographic survey of 1976 HHs and subsample of 682 children (<15 years) and 264 women (15–49 years) in anthropometric survey in four villages	Cohort study	2003	Odds of a woman with 'energy saving' water points closer to home giving birth in any given month was three times greater than a woman without an improved water supply (OR 3.78, p=0.009).	Fair*
Hemson 2007 <sup>26</sup>	South Africa: 1052 children aged 5–17 years from 366 households, in three villages with no piped water supply; two dry flat villages in Limpopo and one hilly village with natural springs in Kwazulu Natal	Mixed methods	NR	17% of children surveyed on recent illness reported fatigue for which 4% had sought treatment. Of children reporting worsened health, 96% described water carrying as tiring, 75% reported fatigue.	Poor* Fair†
Rao 2008 <sup>25</sup>	India: 22 rural women aged 18–45 years from villages about 30–40 km from Pune city, Maharashtra	Cross-sectional survey	NR	PAL‡ of drawing water from a well and using hand pump were categorised as moderate; carrying two containers on the head was categorised as heavy.	Poor*
Borah 2010 <sup>28</sup>	India: 30 rural women with normal blood pressure and temperature aged 21–40 years in Jorhat district of upper Brahmaputra Valley Zone of Assam	Observational study	NR	Compared with walking to water point and drawing water, the return journey with water-filled containers had maximum heart rate (HR) and energy expenditure (EE) for 21–30 age group (115 bpm and 9.56 kJ/min) and for 31–40 age group (113 bpm and 9.24 kJ/min); on basis of average HR and EE, workload for drawing water and return journey classified as moderately heavy; on basis of peak HR and EE, workload for drawing water and return was classified as heavy or very heavy; rating of perceived exertion was highest with the return journey while carrying water, and highly correlated with HR (r=0.84–0.92) for both age groups at all parts of the water fetching cycle.	Poor*
Geere 2010a <sup>46</sup>	South Africa: subgroup of 29 people interviewed, drawn from convenience sample of 39 adults and children fetching water in six rural villages of Limpopo Province	Mixed methods	2008	Rating of perceived exertion significantly correlated with container weight (r=0.52; p=0.011) and path incline (r=0.459; p=0.018) during water carriage.	Poor*
Geere 2010b <sup>46</sup>	South Africa: 39 adults and children observed to fetch water in six rural villages of Limpopo Province	Qualitative	2008	Children link water carriage to tiredness in qualitative interviews.	Good†
Domènech 2012 <sup>47</sup>	Nepal: 120 households equally distributed among 10 selected communities and with at least 2 years of experience with rainwater harvesting	Mixed methods§	2008–2009	Rainwater harvesting reduced water fetching (6.4 hours/day less in the rainy season; 4 hours/day less in the dry season) and allowed energy (calorie) savings.	Fair†

Continued

**Table 6** Continued

First author and date	Population	Study type	Dates	Key finding	Quality
Asaba 2013 <sup>31</sup>	Uganda: survey of 602 (~35%) households in Makondo Parish, and in-depth interviews, focus group discussions and participant observation in four villages	Mixed methods	2011–2012	Over 70% of survey respondents highlighted ‘tiresome’ nature of water fetching. Many added that carrying water required ‘a lot of physical energy’. Among men (22.9%) and women (13.6%), male youths (18.1%), female youths (19.1%), male children (23.7%) and female children (23.1%) carrying water was perceived to cause fatigue.	Poor* Fair†
Robson 2013 <sup>32</sup>	Malawi: 1504 children aged 9–18 years from 12 field sites in each of 3 regions	Mixed methods	2006–2009	Of children citing water carrying as their heaviest load, 5% more girls than boys reported experiencing tiredness in the last week. Supported by qualitative data from adults and children, indicating that children suffer from tiredness and inability to concentrate at school, particularly from being woken at night or very early morning to fetch water.	Poor*†
Bisung 2015 <sup>52</sup>	Kenya: convenience sample of 8 women living in Usoma, 15 km from Kisumu	Qualitative	2013	Children need a lot of energy to push wheelbarrows and carts used for carrying water.	Good†
Zolnikov 2016 <sup>57</sup>	Kenya: 52 semi-structured interviews to examine relationships among primary water gatherers and their families after receiving nearby access to water, in Kitui.	Qualitative	NR	Primary water gatherer ‘very tired and easily annoyed’ prior to the implementation of interventions providing nearby water supply.	Good†
Ayoade 2017 <sup>58</sup>	Nigeria: 800 girls aged 5–15 years in periurban areas of Abeokuta, Ogun State	Qualitative	2013–2014	Respondents reported that they experienced fatigue due to water carriage, which negatively affected their ability to participate in school.	Poor†

\*Methodological quality rating of cohort study or cross-sectional survey.

†Methodological quality rating of qualitative study or reporting of qualitative findings as part of a mixed methods study.

‡Index of total energy expenditure adjusted for basal metabolic rate (BMR).

§Quantitative data reported by Domenech *et al* were water quality testing.

HHS, households.

**Table 7** Water carriage and stress, mental well-being or life satisfaction

First author and date	Population	Study type	Date	Key findings	Quality
Belue 2008 <sup>27</sup>	South Africa: mothers, 9 months post partum aged 17–30 years, Khayelitsha, Western Cape	Cross-sectional survey	1999–2000	Piped water in the dwelling associated with significantly lower perceived stress (PSS); PSS 14.2, (SD 4.8) for piped into dwelling, 19 (SD 7.4) piped water to yard, 17 (SD 6.6) for public standpipe).	Poor*
Devoto 2012 <sup>30</sup>	Morocco: 845 households in Tangiers, not connected to a city water network, comparing subgroup of households reporting above median baseline time fetching water	Cohort study	2007–2008	With subgroup analysis of households reporting above average median baseline water fetching time, no significant effect of allocation to water supply ‘encouragement’ project, or actual connection to piped water supply on (a) summary index averaging 3 scores of mental well-being (over past 7 days respondent felt more often than not, sad/worried/satisfied), and (b) respondent’s rating of life satisfaction level being $\geq 5$ (on 0–10 scale).	Good*
Stevenson 2013	Ethiopia: women from cluster sample of 104 households for free listing, convenience sample of 39 women from three kebeles for ranking exercise, three focus group discussions totalling 30 women from three kebeles, cluster sample of 324 women	Mixed methods	2009–2010	The 24-item water insecurity scale was correlated with time required to fetch water ( $r=0.52$ ; $p<0.0001$ ), and was positively but weakly correlated with psychosocial distress ( $r=0.22$ , $p<0.001$ ), indicating that women who experienced more water insecurity also reported more symptoms of common mental disorders. Qualitative data indicate that social and environmental factors contribute to stress during water carriage.	Poor* Good†
Henley 2014 <sup>36</sup>	Kenya: randomly selected subsample (200 of 1000 participants in health survey) from settlements in Naivasha and Mogotio	Cross-sectional survey	2011	Participants who reported feeling unsafe when they collected water or went to the toilet had increased mean hair cortisol content by 127 ng/g (yes (safe) 607 $\pm$ 282 ng/g; no (not safe) 734 $\pm$ 335 ng/g; $p=0.0370$ ).	Fair*
Zolnikov 2016 <sup>57</sup>	Kenya: 52 semi-structured interviews to examine relationship experiences among primary water gatherers and their families after receiving nearby access to water, in Kitui.	Qualitative	NR	Primary water gatherers: before water interventions easily annoyed; after intervention additional time for discussions with spouse and of school-related achievements and issues with children. Household heads: before interventions angry at lack of water availability, challenged by lack of time for household discussions, unsatisfied with work; after water interventions time for discussions and planning with spouse, made additional money. Children: after intervention school fees available, time with mother and family more frequent, more time for friendships and schoolwork, no time outside of school spent gathering water.	Good†

Continued

Table 7 Continued

First author and date	Population	Study type	Date	Key findings	Quality
Thomas 2018 <sup>44</sup>	Ethiopia: survey and focus groups with 200 households in Welenchiti, Oromia region, and interviews with senior water utility staff	Mixed methods	NR	Most households (64%) felt 'bothered' by collecting water in the previous 7 days, mostly because of having to collect water at night; emotional distress was not significantly associated with accessibility (total water collection time in minutes) of the main water source ( $\beta = -0.03, p=0.677$ ) indicating that a longer time spent collecting water did not increase the intensity of emotional distress.	Poor*†

\*Methodological quality rating of cohort study or cross-sectional survey.

†Methodological quality rating of qualitative study or reporting of qualitative findings as part of a mixed methods study.

mental health and life satisfaction were not included in the analyses. The average one way time to the water source in the case study by Thomas and Godfrey<sup>44</sup> was <3 min.

There is moderate quantitative evidence that perinatal health is associated with water carriage (table 3) and strong qualitative evidence (table 4). Six studies reported different aspects of perinatal health to be associated with water carriage (table 8). Two qualitative papers reported physical strain and non-specific 'health complications' from carrying 20 L water containers on the head during pregnancy<sup>50 52</sup> and one reported mothers' views that being forced to fetch water in late pregnancy led to malnourished children.<sup>55</sup> Quantitative studies reported reduced uptake of prenatal care services,<sup>22</sup> six times greater odds (our calculation) of giving birth in a health facility when a husband provided help with water fetching<sup>38</sup> and almost four times greater odds of giving birth in any given month, among women with an improved water supply closer to their home compared with those without improved water supply.<sup>24</sup> Gibson and Mace<sup>24</sup> described the improved water access as an 'energy saving' intervention which reduced distance to water and women's time spent water fetching. They concluded that the energy saved by the technology did not translate into an improved nutritional status for women, because it supported an increase in birth rates. While the study found a negative consequence of the increased birth rate to be increased childhood malnutrition, it nevertheless indicates a potentially detrimental impact of maternal health associated with water carriage; it suggests that prior to installation of taps the exertion of water carriage affected women's health enough to reduce birth rates, as compared with birth rates post-tap installation. While Gibson and Mace did not include nutritional interventions as possible confounding factors in their multivariable analysis, and McCray's<sup>22</sup> outcome measure could have been affected by recall and therefore misclassification bias, the six studies provide evidence that water fetching could be significantly associated with perinatal health outcomes through behavioural and physiological mechanisms.

There is moderate quantitative evidence and strong qualitative evidence that vulnerable people are at risk of discrimination or physical, sexual and psychological abuse while they collect water (tables 3 and 4). The studies in this review provide rich qualitative evidence in good,<sup>49 51 54 55 57</sup> fair<sup>31 47 48</sup> and poor quality studies<sup>32 50 58</sup> from 31 countries, and good,<sup>30</sup> fair<sup>31 37</sup> or poor<sup>31 32 35 41 42</sup> quantitative evidence from 6 countries (table 9). People may be vulnerable because of age, gender, disability, health status or ethnicity.

There is inconclusive evidence of a relationship between water carriage and self-rating of general health, because of inconsistent findings in the five studies (tables 3 and 4). There is an indication of a dose-response relationship between water carriage and self-rating of health in three<sup>21 23 26</sup> of the five studies reporting

**Table 8** Water carriage and perinatal health

First author and date	Population	Study type	Dates	Key finding	Quality
McCray 2004 <sup>22</sup>	South Africa: 327 HH surveys: mothers of child aged 12–23 months in randomly selected household Kwazulu Natal	Cross-sectional survey	1998	Report that fetching water was daily activity affected by making a trip to the health clinic associated with level of prenatal care utilisation ( $\chi^2=6.64$ , $p=0.036$ ); women two times more likely to use prenatal care services at low level than at an average level ( $1/OR=2.43$ ).	Fair*
Gibson 2006 <sup>24</sup>	Ethiopia: 1548 women (aged 15–49 years) in demographic survey of 1976 HHs; 682 children, 264 women in anthropometric study (four villages)	Cohort study	2003	Odds of woman with access to water points giving birth in any given month three times greater than a woman without an improved water supply (OR 3.78, $p=0.009$ ). Installation of taps did not improve or predict maternal health indicated by anthropometric measures of BMI and MUAC.	Fair*
Ono 2014 <sup>38</sup>	Kenya: 306 mothers aged 18–49 years, who brought their babies to Sisiot Health Center for immunisation within their first year of life, in September to November 2011. Data from 303 respondents (99%) were analysed	Cross-sectional survey	2011	Unmarried women whose sisters helped them fetch water more likely to deliver at health facilities (HF) ( $p=0.042$ ) and married women whose neighbours helped them fetch water less likely to deliver at HF ( $p=0.021$ ) than those without support. Married women, borderline significant ( $p=0.054$ ) association between birth at home and support from husband water fetching; of women who received help from their husband to fetch water, 1 of 20 (5%) gave birth at home, 19 of 20 (95%) gave birth in a HF; women who did not have help from their husband to fetch water, 50 of 211 (23.7%) gave birth at home, 161 of 211 (76.3%) gave birth in HF. Married women more likely to deliver at HF if they did not have the support of sisters-in-law fetching water (OR=2.2, 95% CI 1.0 to 4.7, $n=245$ ; husband helping not in logistic regression model).	Fair*
Mukhulani 2014 <sup>50</sup>	Zimbabwe: respondents of three Bulawayo suburbs	Qualitative	NR	Physical strain and health complications from carrying 20 L container on head while pregnant highlighted in illustrative quote from qualitative data.	Poor†
Bisung 2015 <sup>52</sup>	Kenya: convenience sample of eight women living in Usoma, 15 km from Kisumu	Qualitative (photovoice)	2013	Photograph of pregnant woman carrying 20 L of water on head and holding 10 L used to exemplify association of water carriage with maternal health.	Good†
Ghosh 2016 <sup>55</sup>	India: 79 mothers from 8 groups of 8–10 mothers of at least 1 child under 6, in four villages in the Sundarbans of West Bengal	Qualitative	NR	Mothers did not get sufficient rest during pregnancy and perceived that this led to giving birth to malnourished children. 'The women have to fetch water from a distant source even in their last few months of pregnancy. They force themselves to do so to avoid the quarrels with the mother-in-law'.	Good†

\*Methodological quality rating of cohort study/cross-sectional survey.

†Methodological quality of qualitative study or qualitative findings of mixed methods study. BMI, body mass index; MUAC, middle upper arm circumference.

**Table 9** Water carriage and social vulnerability

First author and date	Population	Study type	Dates	Key finding	Quality
Devoto 2012 <sup>30</sup>	Morocco: 845 households in Tangiers, not connected to a city water network, comparing subgroup of households reporting above median baseline time fetching water	Cohort study	2007–2008	Significant reduction in risk of being in conflict with people from his/her family on water matters with (a) allocation to water supply ‘encouragement’ project (–0.06, p=0.05), which remained significant and decreased further for households with above median baseline time fetching water (–0.09, p=0.10) or (b) actual connection to piped water supply (–0.12, p=0.05), which was similar but not significant for households with above average baseline water fetching time.	Good*
Domènech 2012 <sup>47</sup>	Nepal: 120 households distributed among ten selected communities, with at least 2 years experience of rainwater harvesting	Mixed methods‡	2008–2009	Perceived benefits from rainwater harvesting reported as being particularly helpful to vulnerable groups, described as older people, disabled people and children.	Fair†
Yallow 2012 <sup>35</sup>	Ethiopia: 296 home based care clients living with HIV/AIDS, drawn from two NGOs in Gondar city	Mixed methods	2009	Bivariate analysis indicated that being forced to go far distance associated with unimproved water status (crude OR 3.91, 95% CI 1.13 to 13.47, p<0.05); needing help with walking associated with improved water status (crude OR 0.11, 95% CI 0.01 to 0.89, p<0.05), but not significant in multiple logistic regression; adjusted OR for forced to go far 3.84 (95% CI 0.41 to 35.27); for needing help walking 0.13 (95% CI 0.01 to 1.44).	Poor* Good†
Asaba 2013 <sup>31</sup>	Uganda: survey of 602 (~35%) households in Makondo Parish, and in-depth interviews, focus group discussions and participant observation in four villages	Mixed methods	2011–2012	Water points are sites of positive social interactions, however, fights resulting in verbal and physical attacks were also observed and reported to occur at ‘improved’ water points, particularly at those with queues.	Poor* Fair†
Robson 2013 <sup>32</sup>	Malawi: 1504 children aged 9–18 years from 12 field sites in each of 3 regions	Mixed methods	2006–2009	Hazards of water fetching reported to be harassment, verbal abuse or attack from people, and ‘meeting criminals’.	Poor*†
House 2014 <sup>48</sup>	Various countries§	Qualitative	NR	Case studies indicate that gender-based violence occurs during water fetching in many countries. Violence may be sexual, psychological, physical or sociocultural.	Poor†
Isoke 2014 <sup>49</sup>	Uganda: 127 survey respondents from Bwaise II and Kisenyi III parishes (informal settlements in Kampala). Semi-structured interviews with 10 NWSC staff. Three focus groups, 2 with 12 leaders of the parishes and 1 of 4 NGO members	Mixed methods¶	NR	Reasons cited for choice of tap included securing young children from being sexually abused and preventing children from ‘picking up bad habits from bad company’.	Good†

Continued

Table 9 Continued

First author and date	Population	Study type	Dates	Key finding	Quality
Mugambe 2014 <sup>37</sup>	Uganda: 450 respondents, with 222 from HIV/AIDS affected, 228 from HIV/AIDS non-affected households of rural districts Mpigi and Gomba	Cross-sectional survey	NR	Bivariate analysis: perceptions that fetching water takes a lot of time (OR=2.44; 95% CI 1.65 to 3.61) and requires a lot of energy (OR=1.83; 95% CI 1.26 to 2.67) strongly associated with buying water from water vendors. Multivariable analysis: perception that fetching water takes lot of time (AOR=2.15; 95% CI 1.21 to 3.82), district location (AOR=1.92; 95% CI 1.25 to 2.95), presence of person living with HIV/AIDS in household (AOR=0.58; 95% CI 0.38 to 0.88) significant predictors of buying water from vendors.	Fair*
Mukhulani 2014 <sup>50</sup>	Zimbabwe: respondents from three suburbs in Bulawayo affected by water scarcity	Qualitative	NR	Sexual assault and harassment reported at water points, during early morning queuing for water, or at night when travelling to boreholes 500 m–2 km away.	Fair†
Schatz 2014 <sup>51</sup>	South Africa: 30 women aged 60–75 years and impacted by HIV in some way, from phase I of the 'Gogo Project', in rural subdistrict	Qualitative	NR	Fetching water is an activity associated with the respondents' (older women) own health and level of family support.	Good†
Subbaraman 2015 <sup>54</sup>	India: 40 adults of Mumbai slum; 3 focus groups (FGs) 6–9 women; 3 FGs 6–9 men	Qualitative	2011	Reports of social conflict and extortion when bringing water containers home.	Good†
Ghosh 2016 <sup>55</sup>	India: 79 mothers from 8 groups of 8–10 mothers who had at least one child below 6 years of age across 4 villages in three blocks in the Sundarbans region of West Bengal	Qualitative	NR	Mothers did not get sufficient rest in pregnancy, perceived that this led to birth of malnourished children. 'The women have to fetch water from a distant source even in their last few months of pregnancy. They force themselves to do so to avoid the quarrels with the mother-in-law'. Some beaten by in-laws.	Good†
Cook 2016 <sup>40</sup>	Kenya: 387 households near Kianjai, north-central Kenya	Cross-sectional survey	2013	Water sources are a cause of social conflict. Proportion of respondents who thought using water source would be 'somewhat' or 'very' likely to lead to conflict: public well 0.69, public borehole 0.51, public piped connection 0.56, surface, other public 0.62. Among well-owners, 85% reported allowing neighbours to use well, of these 28% said that sharing led to conflict with neighbours.	Poor*
Krumdieck 2016 <sup>41</sup>	Kenya: 323 women at 33 weeks gestation, of mixed HIV status, recruited from seven clinics in Nyanza province	Quantitative	2014–2015	Water acquisition posed psychological stress and physical risk, 77.3% stating that they felt 'somewhat or strongly concerned' for their physical safety during trips for water.	Poor*
Zolnikov 2016 <sup>57</sup>	Kenya: 52 semi-structured interviews among primary water gatherers and their families after receiving nearby water access	Qualitative	NR	Primary water gatherers report feeling 'scared and fearful when gathering water, unhappy with water-gathering situation'	Good†

Continued

Table 9 Continued

First author and date	Population	Study type	Dates	Key finding	Quality
Ayoade 2017 <sup>58</sup>	Nigeria: 800 girls aged 5–15 years in periurban areas of Abeokuta, Ogun State	Qualitative	2013–2014	456 (55%) reported sexual assault and/or harassment; 99 (11%) reported physical punishment by parents or guardians when containers got lost or exchanged at water points; 184 (23%) reported punishment by parents or guardians who believed they were wasting water; 122 (14%) reported fear of returning home with empty containers.	Poor†
Dapaah 2017 <sup>42</sup>	Ghana: 120 survey respondents in Ga-Mashie, Accra and 80 in Madina, Accra	Mixed methods**	NR	Incidence of fights at water collection points 102 (85.0%) in Ga-Mashie; 34 (42.5%) in Madina; 136 (68.0%) in total.	Poor*

\*Methodological quality rating of cohort study or cross-sectional survey.

†Methodological quality rating of qualitative study or qualitative findings of a mixed methods study.

‡Quantitative data reported by Domenech *et al* were water quality testing.

§Sudan, DRC, Solomon Islands, Liberia, Guinea, Sierra Leone, Kenya, India, Cameroon, South Africa, Tanzania, Uganda, Zambia, Haiti, Afghanistan, Cambodia, Somalia, Philippines, Nigeria, Ghana, Mozambique, Pacific Islands, Pakistan, Angola, Malawi, Sudan, Iran, Nepal, Timor-Leste, Bangladesh, Sri Lanka.

¶Quantitative data reported by Isoke and Van Dijk were not analysed for association with health outcomes.

\*\*Qualitative data were not about health outcomes.

AOR, adjusted OR; NGO, non-governmental organisation; NWS, National Water and Sewerage Corporation.

general health of water carriers, with greater amounts of time spent water fetching linked with poorer health for both children and adults (table 10). These findings were inconsistent with those of Geere *et al*,<sup>43</sup> who found that adults who currently or previously carried water, had a better (lower=healthier) mean general health rating score than adults who never carried water, while children who currently carried water reported better, and children who previously carried water reported worse health, compared with children who had never carried water. In qualitative data from an earlier pilot study, Geere *et al*<sup>46</sup> found that some children linked water carriage to better health and stronger resilience to diseases such as ‘influenza’, others to meeting basic needs and some to experiencing unfair workloads.

The inconsistencies may be due to different methods used for participants to rate their general health, and differences in confounding factors incorporated into the analyses. In the three of four studies which attempted to scale or categorise health status,<sup>21 23 26</sup> recall of occasions of illness or comparison of current to previous health status was required of respondents. This may introduce bias or error to the classification of health status, weakening internal validity of the studies and rendering the findings inaccurate.<sup>17</sup> Self-rated health ‘today’ on a simple 5-point scale has been found to have high test-retest reliability and to be an excellent predictor of future health in some studies, however, reliability of self-rated health status has also been shown to be affected by age, income and occupation in some populations.<sup>67</sup> Hemson’s<sup>26</sup> findings may therefore have been influenced by recall and confounding factors, because the statistics presented are descriptive and lack analysis of the effect of variables such as age, gender and socioeconomic status. These variables were considered in the regression analyses reported by Bour,<sup>21</sup> Foggin *et al*,<sup>23</sup> and Geere *et al*,<sup>43</sup> with Foggin *et al* reporting a very strong association between increased time spent water fetching and poorer general health. However, other potential confounding factors which were not included in analyses, such as hygiene practices, access to healthcare or sanitation coverage, could have influenced the results in all studies. No studies used a longitudinal cohort design to determine a temporal relationship between water fetching and health status, and all could have been affected by confounding factors which were not included in analyses.

## DISCUSSION

This is the first systematic review of the association of the work of water carriage with the health of water carriers. Forty-two studies were included in the review. Direct detrimental health impacts were mainly reported, such as increased pain, fatigue and stress. Indirect detrimental health impacts were also reported and were related to perinatal health and social vulnerability. These included serious health issues such as physical abuse and rape. The ability of the studies reporting quantitative data to

**Table 10** Water carriage and general health

First author and date	Population	Study type	Date	Key findings	Quality
Buor 2004 <sup>21</sup>	Ghana: 210 females aged 12+ years in Kumasi; 90 from urban 'core', 120 from urban periphery survey	Cross-sectional survey	2001	During water scarcity: ill once every 2 weeks (fetching water $\geq 4$ hours 39.2%; 2–3 hours 19.3%; $< 2$ hours 21.3%); ill once a month (fetching water $\geq 4$ hours 31.4%; 2–3 hours 26.6%; $< 2$ hours 27.7%); ill once in 3 months (fetching water $\geq 4$ hours 19.6%; 2–3 hours 41.3%; $< 2$ hours 31.9); ill rarely (fetching water $\geq 4$ hours 9.8%; 2–3 hours 12.8%; $< 2$ hours 19.1%); multiple regression: beta-coefficients total sample ( $-0.255$ ; $p=0.000$ ), core ( $-0.261$ ; $p=0.011$ ), and periphery ( $-0.293$ ; $p=0.003$ ). Type of regression model not stated. If multiple linear regression, for each extra hour of water fetching, health status score reduced by 26%–29%. However, health status measured on 4-point categorical scale (1=sick once every 2 weeks, 4=rarely sick), for which proportional odds regression is more appropriate. This would mean that for each hour spent water fetching, the likelihood of going from a lower level of the outcome variable (higher frequency of illness) to the next (lower frequency of illness) reduces by 25%–29%.	Poor*
Foggin 2006 <sup>23</sup>	Tibet: herders in Sanjiangyuan region, Tibetan Plateau, southwest Qinghai Province; 50 families in Suojia Township, 49 in Zhaha Township	Cross-sectional survey and qualitative	2002	Tibetan pastoralists who spend $> 15$ min collecting water are almost 10 times more likely to report being ill in the past month than those spending $\leq 15$ min (OR=9.853; $p \leq 0.001$ ).	Poor* Good†
Hemson 2007 <sup>26</sup>	South Africa: 1052 children aged 5–17 years from 366 households, in three villages with no piped water supply; two dry flat villages in Limpopo, one hilly village, with natural springs in Kwazulu Natal	Cross-sectional survey and qualitative	NR	Compared with children collecting water 0–13 hours per week, smaller proportions of children collecting water for $\geq 14$ hours pw rated their health as 'improved' (0–13 hours 42%; $\geq 14$ hours 37%) or the same (0–13 hours 53%; $\geq 14$ hours 45%) and a greater proportion as worse (0–13 hours 5%; $\geq 14$ hours 19%). Of children reporting worsened health, 77% spent $\geq 14$ hours pw collecting water and 87% stated that their health was worsened by collecting water. Of children who said their health had got worse 82% reported collecting water $> \text{once a day}$ vs 18% collecting water once a day. Of children reporting their health as improved or the same, 56% collected water $> \text{once a day}$ , 44% collected water once a day.	Poor* Fair†

Continued

**Table 10** Continued

First author and date	Population	Study type	Date	Key findings	Quality
Geere 2010 <sup>b</sup> <sup>46</sup>	South Africa: 39 adults and children observed fetching water, six rural villages, Limpopo Province	Qualitative	2008	Children linked water carriage and health in various ways, including feeling 'better and healthy' or having greater resilience to diseases like influenza, as a result of the exercise required for water carriage. Children also related health to being able to participate in activities such as water fetching, as well as to having basic needs met and experiencing fair workloads.	Good†
Geere 2018 <sup>43</sup>	South Africa, Ghana, Vietnam: 1 adult and 1 child from 673 households with at-house and off-plot water supply	Cross-sectional survey	2012–2013	Adults who previously carried water had a better (lower=healthier) mean general health score than adults who never carried water ( $\beta=-0.58$ , 95% CI $-0.80$ to $-0.35$ , $p<0.001$ ) and adults who currently carried water had a better mean general health rating score than adults who had never carried water ( $\beta=-0.91$ , 95% CI $-1.12$ to $-0.70$ , $p<0.001$ ). Children who currently carry water had a better mean score rating for general health than children who had never carried water ( $\beta=-0.20$ , 95% CI $-0.37$ to $-0.31$ , $p=0.003$ ). Children who previously carried water had a worse mean score rating for general health ( $\beta=0.39$ , 95% CI $0.02$ to $0.75$ , $n=10$ ).	Fair*

\*Methodological quality rating of cohort study or cross-sectional survey.

†Methodological quality rating of qualitative study or reporting of qualitative findings as part of a mixed methods study.

demonstrate a cause and effect relationship is limited because of study design and fair or poor methodological quality. The only cohort study in the review rated as good<sup>30</sup> was of limited value, as in the main analyses of the health effects of 'encouragement' and actual household connection to piped water supply, people carrying water by container were not disaggregated from those connected by hose to a public tap or neighbour, the health outcome measures reported for relevant subgroup analyses were limited and confounding factors did not include other forms of manual labour. A greater number of studies reporting qualitative data were rated as having good methodological quality, and while these provide insight into the lived experience of fetching water, they cannot provide strong evidence of a causal relationship, as the actual experience of pain or other health effects may be mediated by confounding factors and bias. Overall, the evidence in this review indicates that the work of water carriage is more often associated with harm rather than benefit to the water carriers' health. Our findings indicate that the health outcomes associated with water carriage create barriers to achieving the targets of many of the SDGs.

Qualitative studies clearly indicate that water carriers experience pain and feel exposed to risk of injury during water carriage, which is commonly performed by carrying containers on the head. The findings are supported by Lloyd *et al*,<sup>68</sup> who reported that discomfort in the neck was, in all cases, the cause of early termination of head-loading trials during a laboratory experiment. Geere *et al*<sup>43</sup> proposed that the pain pattern they observed to be associated with water carriage might indicate referred pain as a consequence of tissue deformation under compressive loading, or long-term structural changes such as cervical spondylosis. Evidence of advanced cervical spondylosis has been reported among porters and people who apply loads to the head (head loading),<sup>69–71</sup> suggesting that this common method of water carriage may be sufficient to cause structural changes in bone and the soft tissues of the spine. Such changes have been proposed in experimental studies to occur as a consequence of biomechanical stress and strain.<sup>72</sup> Particularly in the cervical spine, spondylosis may lead to neurological impairment, such as radiculopathy or myelopathy, and related disability.<sup>73–74</sup> However, none of the studies reporting pain or injury affecting water carriers were longitudinal cohort studies. Hence, it remains unknown whether the loading patterns typical of domestic water carriage, by head loading or other methods, are sufficient to have important long-term effects on the musculoskeletal system and to increase risk of neurological compromise. This question is particularly important for populations in sub-Saharan Africa, where other risk factors for myelopathy, including nutritional or infectious diseases such as HIV, tuberculosis or schistosomiasis, are also common<sup>75–77</sup> and may increase susceptibility to adverse impacts of head loading. It is also important to recognise that many people will carry diverse loads in addition to water,<sup>60</sup> and future studies

should include detail of other head loading and manual labour as potential factors confounding the effects of water carriage.

No studies attempted to conduct any detailed clinical assessment of their study participants,<sup>78</sup> or reported excluding participants with long-term health conditions which might cause pain and modify an association between symptoms and water carriage. This may be due to the practical and ethical challenges of conducting clinical assessments in areas of limited health services coverage, the likely situation in many areas where water carriage studies would typically be conducted.<sup>6</sup> However, future studies would be strengthened by incorporating some aspects of clinical assessment to supplement self-reported health outcomes. For example, a medical history could be combined with evaluation of whether movement, compression stress or palpation of pain sensitive structures provokes symptoms comparable to those experienced during water carriage.<sup>79</sup> This would help to identify a likely cause of symptoms and could confirm whether mechanical loading during water carriage is a plausible mechanism of pain production in study participants.

This review has found moderate quantitative and strong qualitative evidence that tiredness or fatigue is associated with water carriage. Head loading by African women has been described as an energy efficient way of carrying loads.<sup>80–81</sup> However, one study tested the 'free ride' hypothesis for head loads compared with back loads, and found that it was not generalisable, with significant individual differences in energetic cost.<sup>82</sup> In larger households, or those caring for young children, aged parents or people living with disability or long-term conditions, their need for water may be high and water carriage may become a demanding daily chore, particularly if it falls on one woman or her children. Differences in the capacity of individuals to meet their household's need for water will influence water security and could exacerbate interhousehold and intercommunity inequalities of water access, a direct challenge to SDG 6 target 6.1 'universal and equitable access to safe and affordable drinking water for all'.<sup>5</sup>

We found inconclusive quantitative and strong qualitative evidence that stress is associated with water carriage. Qualitative evidence highlighted that the experience of stress associated with water carriage could be due to reduced family time and poorer interpersonal relationships, conflicts which arise in the community or at home over water use and domestic tasks, the physical challenges of collecting water and lack of safety. Water fetching is also indirectly linked to stress, by increasing water insecurity, and feelings of worry or shame from inability to keep oneself or one's children clean, or complete expected household chores such as laundry, cleaning and cooking. The one good quality cohort study in this review did not find a significant effect of connection to a piped water supply on respondents' mental health or life satisfaction, however, their mental health index was derived from the average of three separate measures of well-being, and its

reliability and validity for use in the study population is not clear. While socioeconomic confounding factors were included in the analyses, other factors which may have also affected mental health and well-being in the population studied, were not included in the analysis. Overall, our findings are similar to a review of water insecurity and psychosocial stress,<sup>83</sup> and highlight that reducing the work of water carriage has potential to benefit women's and children's mental health in settings where water carriage is physically challenging, unsafe or exacerbates water insecurity. This aligns with SDG target 3.4 to 'promote mental health and well-being'<sup>6</sup> and further good quality cohort or intervention studies, using valid and reliable outcome measures of stress, mental health and well-being are warranted.

The moderate quantitative and strong qualitative evidence that water carriage can affect perinatal health and reduce uptake of health services is particularly relevant to SDG 3 targets 1 and 2, to reduce maternal and new born deaths, and 7, ensure access to reproductive healthcare services. Fetching water also sets the scene in which health risks due to social vulnerability are realised. Vulnerable people include women, children, displaced people, people with disability and people living with HIV/AIDS. It is likely that cases of abuse are under-reported, due to shame and fear of further discrimination or reprisals against the victim or their family, and ineffective or inappropriate policing and support services.<sup>48</sup> Older adults are also vulnerable, as they may not be capable of collecting enough water from off-plot sources because of age-related health problems, and may lack support from younger family members for fetching water.<sup>84 85</sup> Future studies should investigate how to reduce social vulnerability and ensure *safe access* to safe water, and are needed to strengthen the existing evidence base and identify ways to meet the 'universal' aspect of SDG 6, target 6.1.

Study findings differ on the association between general health and water carriage. Apart from differences in study design, the perceived and reported general health impact of water carriage may also be mediated by whether the work is perceived as 'normal', whether it allows basic needs to be met and by how well the workload matches the water carrier's physical capacity for work and the comparative workload of other people.<sup>46</sup> In the study which reported a rating of health 'today',<sup>43</sup> the association of better health with current or past water carriage might indicate a selection process, whereby healthier people are allocated the task of fetching water. It may also indicate a beneficial health effect of regular physical activity undertaken since adolescence.<sup>86</sup> Overall, the findings on general health from studies in this review are inconsistent and therefore provide inconclusive evidence. However, in light of this review's findings in relation to other domains of health, further research with longitudinal cohort studies is warranted.

Our review has used a sensitive search strategy to identify published reports in academic and grey literature. While one good quality cohort study evaluating the

impact of connection to piped water supply was found, its findings were of limited value for the review. A limitation of our review is that we did not contact study authors for additional information or data. All other studies were either qualitative or used cross-sectional surveys, and we therefore cannot make causal inferences. However, the qualitative studies included in this review provide insight into people's experiences of water fetching and the mechanisms by which it might affect their health, and together with the substantial number of cross-sectional studies reporting that water carriage is negatively associated with health outcomes, indicate that further good quality research is warranted.

The design of future studies should ideally evaluate the temporal relationship between water carriage (exposure) and health (outcome) to evaluate cause and effect, or use randomisation and control groups or villages to reduce risk of confounding and bias. They should also include multivariable analyses of important potential confounding factors, such as socioeconomic level, health status and comorbidities, manual labour and carriage of loads other than water.<sup>87</sup> Studies should incorporate standardised, valid and reliable methods of exposure and outcome measurement, including measured time spent carrying water, weight of water carried, frequency of water carriage, years of exposure and methods of water carriage. Health outcome measures should be piloted for reliability and validity of use in the study populations, and include severity, duration, location and functional impact of pain, as well as indicators of fatigue, stress, mental health and general health, social vulnerability and perinatal healthcare access. Clinical assessment by trained health workers could supplement self-reported outcome measures to support better evaluation of the health status of study participants against selection criteria, at baseline assessment and follow-up. While the challenges of limiting the effects of confounding and bias in WASH research are well recognised,<sup>88</sup> a stronger body of evidence derived from good quality studies with comparable health outcome measures will allow future reviews to better evaluate risk of bias, more precisely estimate measures of treatment or intervention effect and conduct sensitivity analyses to reduce risk of overall bias.

Through its association with pain, fatigue, stress and reduced access to perinatal healthcare services, the existing evidence suggests that water carriage is a potentially important barrier to achievement of many health targets set for SDG 3. Because in most households of low-income and middle-income countries, it is women and girls who fetch water for household use, it will also compromise SDGs related to gender equality, quality education for all and reducing inequalities. Because water is essential for life, but fetching it is often not safe, water carriage is also a barrier to ensuring safe and inclusive societies, and decent work for all, a further challenge to reducing poverty in all its forms. However, it is important to recognise that water may be carried in addition to other loads, and it may not be the heaviest or key

portage task leading to health issues. Combined, all of these factors reduce the likelihood of achieving SDG 6 target 1 by 2030: 'universal and equitable access to safe and affordable drinking water for all'.

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**Contributors** J-ALG conceived of the review, completed the electronic data base searches, selected papers to include in the review against selection criteria, extracted data, appraised articles reporting qualitative and quantitative data, wrote the first draft of the paper, reviewed subsequent drafts and reviewed and approved the final draft; MC conceived of the review, contacted experts in the field of water and health, provided translation of Swedish papers, reviewed drafts and reviewed and approved the final draft of the paper; JHG appraised articles reporting quantitative data, reviewed drafts and reviewed and approved the final draft of the paper; CCH appraised articles reporting qualitative data, reviewed drafts and reviewed and approved the final draft of the paper; PRH selected papers to include in the review against selection criteria, provided translation of French papers, appraised articles requiring consensus on quality rating, reviewed drafts and reviewed and approved the final draft of the paper.

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