Review Paper

Environmentally sustainable WASH? Current discourse, planetary boundaries and future directions

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ABSTRACT

The significant challenge of achieving safe, reliable and continuous service delivery has been a focus of the water, sanitation and hygiene (WASH) sector in recent years, with less attention given to other important sustainability considerations such as environmental sustainability. The agenda set by the Sustainable Development Goals prompts a wider lens, bringing water resource management and ecosystem conservation together with water and sanitation access targets in one integrated goal. As we grapple with our approach to this new agenda, it is timely to reflect on how we, as a sector, engage with environmental sustainability. This paper reviews recent literature at the intersection of WASH and environmental sustainability to identify current themes and future directions. Analysis of academic and non-academic sources was undertaken and then situated with reference to the planetary boundaries framework as a useful lens to ground the socio-ecological systems and processes upon which environmental sustainability depends. Findings point to both opportunities and gaps within current sector thinking, which can drive leadership from knowledge and research institutions towards better integration of access and environmental sustainability imperatives.

Key words | environmental sustainability, planetary boundaries, reuse, Sustainable Development Goals, WASH, water security

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INTRODUCTION

Within international development aid, the dominant focus of the water, sanitation and hygiene (WASH) sector has been on social, health and economic needs and drivers, with 'sustainability' often defined as continuation of services (Mehta & Movik 2014). The environmental sustainability implications of improving access are given less focus. Yet they are significant; if we continue to use dominant paradigm approaches to expanding service delivery for the 663 million people currently without access to safe water and the 2.4 billion without access to improved sanitation (WHO/UNICEF 2015) while keeping pace with population growth, there will be significant impacts across a range of ecological systems and the resources they provide. This will threaten our ability to provide equitable services for all into the future.

To date, service delivery paradigms have been informed by the experiences of developed countries and typically focused on extractive water infrastructure and 'end of pipe' sanitation solutions. These models have addressed access issues, but with costs to ecosystem and resource integrity (Gleick 2003; Poustie & Deletic 2014). In the global water sector there is a shift occurring towards solutions that improve the productivity and efficiency of water use (Brooks & Brandes 2011). This approach has the potential to better integrate ecosystem and resource sustainability concerns compared with historic approaches, but is a relatively recent shift in developed countries and is yet to be meaningfully taken up in the international development WASH sector (Brooks & Brandes 2011). For this sector, it is imperative

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to consider ways to move beyond business as usual approaches to better integrate environmental considerations with access objectives.

In 2015 the most recent global development agenda emerged, embracing new visions and objectives in the form of the Sustainable Development Goals (SDGs) (United Nations 2015). In the SDG framework, WASH-related targets (within SDG6) have been broadened as compared with their Millennium Development Goal (MDG) predecessors. There is a stronger emphasis on universal and equitable access (informed by the human rights to water and sanitation) and the need to consider service access imperatives with reference to broader water resource management considerations. The broader agenda encompassed in SDG6 reflects a recognition of the central importance of environmental considerations in sustainable water and sanitation service delivery, with a particular focus on the interlinked areas of water quality, water efficiency, integrated water resource management (IWRM) and water-related ecosystems.

As policy makers, practitioners and researchers widen their focus in line with the SDG agenda, it is timely to reflect on the way the WASH sector engages with environmental sustainability. This paper offers a review of current discourse at the intersection of WASH and environmental sustainability to identify themes and consider future directions that might best support, rather than threaten, a safe and sustainable planet. First, the approach is described. This includes articulating how environmental sustainability has been defined for the purposes of the review. We introduce the planetary boundaries framework (Rockström *et al.* 2009) as a means to ground this definition, and we describe the process of discourse analysis. Themes identified in current literature are then presented and critically discussed. Finally, future directions for the sector are proposed, informed by an assessment of current themes against the planetary boundaries framework. The planetary boundaries framework sets out nine interlinked earth system boundaries in which human society can continue to thrive, thereby defining a 'safe operating space for humanity' (Rockström *et al.* 2009; Steffen *et al.* 2015). For this review, this framework both offers a synthesizing framework for engaging with critical questions of environmental sustainability, and advocates an imperative to do so.

APPROACH

Defining environmental sustainability and planetary boundaries

The definition of environmental sustainability adopted for this review incorporates conservation of both natural *resources* and *ecosystems*. A resource lens prompts consideration of the need to manage the natural resources on which human societies depend in a way that enables continuity of services in perpetuity for future generations. Including ecosystem conservation reflects both the interdependencies of ecosystems and natural resources, and their intrinsic value. This definition draws on the well-recognized Brundtland report conception of environmental sustainability as 'meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them' (WCED 1987), and that of Morelli (2011) with its explicit addition of the need to conserve biological diversity:

> '*environmental sustainability could be defined as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity*'.

For the WASH sector, contributing to environmental sustainability therefore requires managing the quantity and quality of resources (such as fresh water) in a way that ensures their ongoing availability now and for future generations, and does not threaten the health of ecosystems. It is important to note that this requires consideration of both local and wider-scale processes, given resource and ecosystem dynamics occur locally, regionally and globally.

The planetary boundaries framework aligns with this definition in its recognition that the health of earth system processes (across scales) dictates the capacity for human populations to survive and thrive. First proposed by Rockström *et al.* (2009) and since refined and re-published (Steffen *et al.* 2015), it sets out nine interlinked biophysical processes that regulate earth system functioning: climate

change; biosphere integrity (biodiversity loss); freshwater availability; land use change; biochemical flows (nitrogen and phosphorus); ocean acidification; stratospheric ozone depletion; atmospheric aerosol loading; and novel entities (chemical pollution). The framework is informed by significant bodies of work across ecological economics, earth system science and resilience (Rockström *et al.* 2009). For each of the nine earth system processes, ongoing research is attempting to define thresholds of human impact beyond which abrupt environmental changes may threaten the earth's capacity to support human populations (Steffen *et al.* 2015). Figure 1 presents the planetary boundaries framework and current assessment, showing that four of the nine boundaries have been crossed as a result of human activity: climate change; biosphere integrity; land-system change; and biochemical flows (Steffen *et al.* 2015).

By quantifying these thresholds of human impact, the framework defines a 'safe operating space for humanity' (Rockström *et al.* 2009). This 'safe operating space' is a key conceptual advancement on previous framings of ecological limits as it provides a way to conceptualize what 'sustainable' looks like from a whole-of-planet perspective as an alternative to sectoral approaches focused on minimizing negative externalities (Rockström *et al.* 2009). Further, it makes it clear that deep and widespread transformations are needed to remain within the 'safe operating space', with four of the earth system processes included within the framework already transgressing their safe limits (Steffen *et al.* 2015).

In identifying a set of tangible earth system processes critical for planetary health, the planetary boundaries framework also grounds the otherwise slightly illusive concept of environmental sustainability. Reflecting this, the framework is becoming more widely used in sustainable development discourse including in global policy dialogues related to the SDGs (Griggs *et al.* 2013; Pisano & Berger 2013; Hajer *et al.* 2015). In line with this and taking a sectoral lens, this review draws on the framework as an analytical tool for promoting consideration of future needs and directions for WASH. Five of the nine planetary boundaries are closely connected to WASH, as described in detail below, including three that have already been transgressed.

Importantly, the authors believe that the need to strive for environmental sustainability does not override the

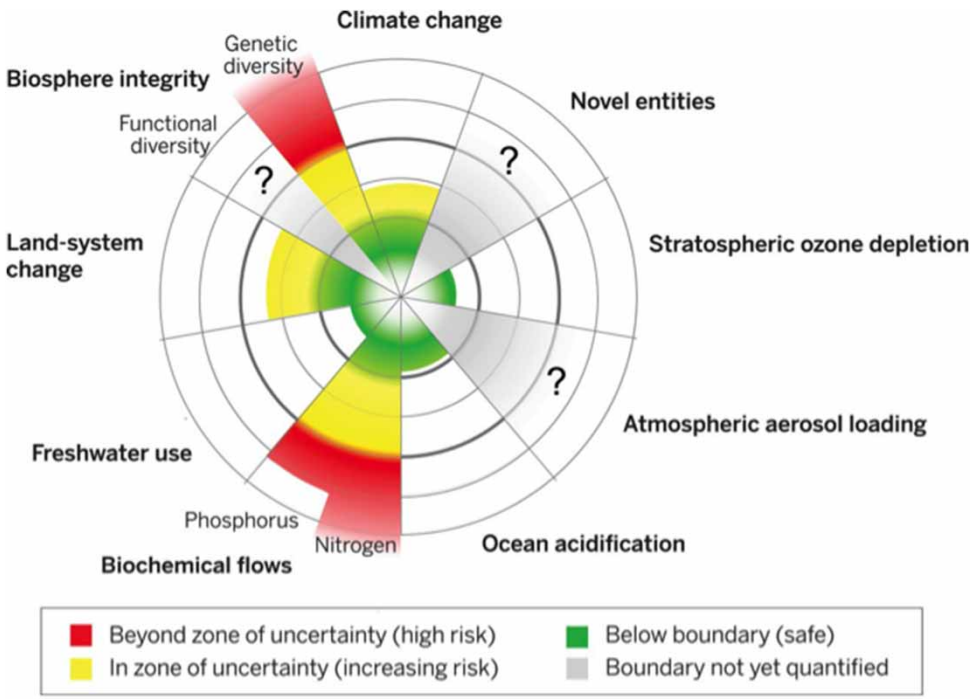

Figure 1 | The planetary boundaries framework and current assessment (Steffen *et al.* 2015).

urgent and critical need to improve the situation for those currently without water and sanitation services. Rather, we assert that progressive realization of the human rights to water and sanitation must continue apace, within a framework that supports environmental sustainability.

Literature analysis

Our approach was to review and analyse environmental sustainability concepts in recent (2010–2016) academic and non-academic WASH sector literature. Recognizing the role that literature, and the discourse contained within it, play in constructing our realities (Phillips & Hardy (2002) cited in Onwuegbuzie & Frels (2014)), a review of this nature helps us to reflect on what we (as a sector) are focusing on and making meaningful. Specific analysis techniques included both content analysis (deductive and inductive coding and counting of codes) and thematic analysis (identifying relationships and their links to the overall context), as described by Onwuegbuzie *et al.* (2012) and explained in further detail below.

The first stage involved extensive searching of academic (peer reviewed journal articles) and non-academic (grey) literature to identify relevant material. Journals with a particular WASH focus were targeted, as were the sites of 18 sector institutions known for undertaking research and/or knowledge management activities. In addition, searches in a variety of academic databases and through both Google Scholar and Google were undertaken to identify further material. Search strings included combinations of phrases relating to 'environmental sustainability', 'water supply', 'sanitation' and 'WASH' depending on the target site. The initial search identified more than 2,400 sources, of which 176 were found to be relevant to our inquiry based on appraisal of titles, abstracts and (if necessary) introductory content (Appendix 1, available with the online version of this paper). During this appraisal process, an initial identification of themes was undertaken for use in subsequent coding.

Documents selected for this stage of analysis were those that provided commentary on, or insight into, the ways the WASH sector approaches research, policy and programming with respect to environmental sustainability. In other words, they enabled an analysis of what topics and ideas are considered important as well as accepted 'ways of doing things' at a sector or programmatic level. Excluded from the analysis were project design documents and reports as well as highly technical papers about specific aspects of technologies. Some material that focused on technologies was included in instances where technologies were explored within a broader discussion of environmental sustainability. We maintained a core focus on literature that was substantially concerned with domestic water supply and sanitation in the developing world, rather than material that incidentally mentioned services within a discussion of water resource allocations and management or climate change. Unsurprisingly, however, many of the sources selected do sit at the interface of WASH and water resource management or climate change, given the close relationship between service delivery and these environmental dynamics.

The second stage involved content analysis and coding of each of the 176 sources based on titles, abstracts, executive summaries and a rapid scan of full text using: (i) themes identified during the initial search phase; (ii) additional content-driven themes that emerged during the coding process (using an iterative process to apply emerging themes to previously coded material); and (iii) themes relating to selected analytical lenses including SDG6 targets and planetary boundaries. Coding was done by one researcher using Mendeley reference management software and Excel, and reviewed by a second researcher. In total 62 codes were used, which were later grouped into a smaller number of themes based on similarities between codes (Appendix 2, available with the online version of this paper). This coding process facilitated a quantitative assessment of themes present in the literature to identify patterns in topics of interest and co-occurrence. Also during this stage, a subset of the 40 sources that provided more in-depth insight into identified themes were selected for closer reading and analysis.

The final thematic analysis stage, based on in-depth review of the 40 selected sources, elucidated themes to enable nuanced analysis of how areas of interest were presented and discussed. These were then considered with reference to the planetary boundaries framework to prompt identification of areas where opportunities exist to increase focus and action on environmental sustainability. This process was also supported by reflecting on the relevance of themes and proposed future directions with reference to SDG6.

Limitations

A first limitation of the review is that it only includes English language literature and therefore may have missed relevant and insightful material. Related to this, the focus was on aid and development WASH literature, so sources from national and subnational levels that may present different themes and discourses, informed by different cultures and contexts, were not considered. In addition to the necessity of reviewing a manageable quantum of material, the rationale for this focus was the fact that across diverse international contexts, aid sector literature is influential in driving how WASH service delivery is approached, so it is worthy of analysis in its own right.

A further limitation is the inherent risk in any literature search process that relevant sources may be missed. This is particularly the case for a topic as broad as environmental sustainability. Efforts were made to triangulate search results by using variations of keywords in search strings (across target databases and organizational sites) to check whether any new relevant material emerged. Despite these efforts, it is reasonable to assume that some relevant material was missed.

Finally, the analysis leans more towards practice than theory, given that this is the dominant focus of WASH sector literature. As such, the review offers valid and valuable insight into sector discourse, but does not engage with potentially relevant theoretical explorations of, for example, the links between water, the natural environment, politics and power.

OVERVIEW OF LITERATURE

The 176 sources reviewed through the second stage process gave relatively equal attention to water and sanitation, with approximately 30% focused on each and the remaining 40% covering both. The split between academic and grey literature was relatively equal. The representation of different regions in the reviewed literature shows 42% of sources taking a global or cross-regional perspective, 22% focused on Africa, and smaller proportions considering other regions across South Asia (13%), East Asia (12%), Latin America (8%), the Middle East (2%) and the Pacific (1%). There was a slightly stronger focus on urban (22%) compared with rural areas (14%), though 39% addressed both. It is noteworthy that a quarter of all sources did not explicitly focus on either urban or rural contexts, indicating a more conceptual focus.

From the coding process, six topic areas emerged as the most strongly represented in reviewed sources: water security; water resource management; climate change; environmental pollution arising from inadequate sanitation; reuse; and environmentally oriented technologies (for instance technologies represented as having strong environmental credentials such as use of locally sourced materials, low energy use or the facilitation of reuse). The numbers of sources that focused on each topic, and the proportions of the reviewed literature that focused on each topic, are shown in Figure 2. Figure 3 shows the proportions of academic and grey literature for each topic, indicating a stronger representation of academic material across technology, reuse and sanitation pollution topic areas, and a greater contribution from grey literature sources on climate change, water resource management and water security.

These topics informed identification of themes in current literature, and as such most of them are elaborated below. It is, however, important to note two points. Firstly, while technologies were represented in a fifth of the reviewed literature, there was strong overlap between this material and other themes including reuse (with more than half these sources also discussing reuse opportunities) and limited additional insight was offered by a more specific review of technology-focused material, so we did include this as an emerging theme. Secondly, the distinction made between water security and water resource management requires explanation. While these two topic areas obviously overlapped, WASH literature typically focused on water security for people (as discussed below) and only a third of the water security literature ($n = 21$) explicitly considered water security as linked to water resource management. For this reason they were treated as two distinct topic areas, however insights from sources with a specific water resource management focus did not add value to the in-depth analysis, and this material is therefore reflected within the elaboration of water security.

EMERGING THEMES

This section presents and discusses four themes which relate to the topic areas described above and draw from

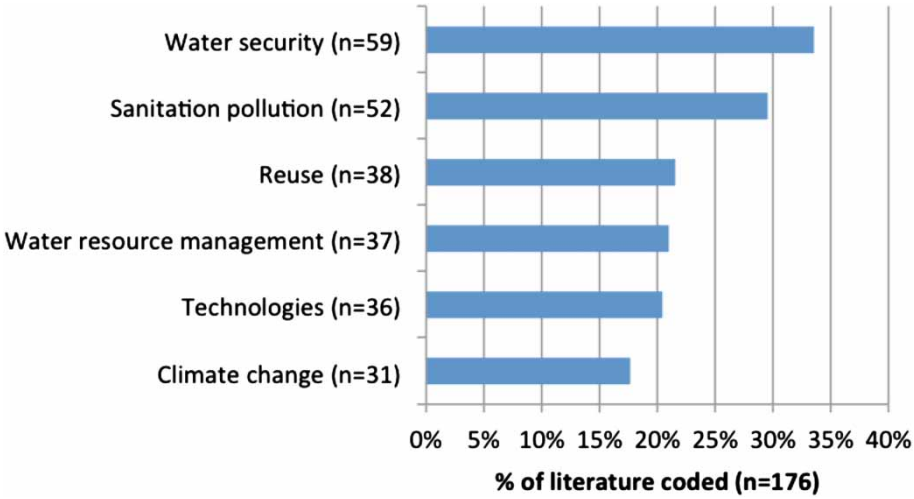

Figure 2 | Common topics in reviewed literature (note that documents may be represented across multiple categories where applicable).

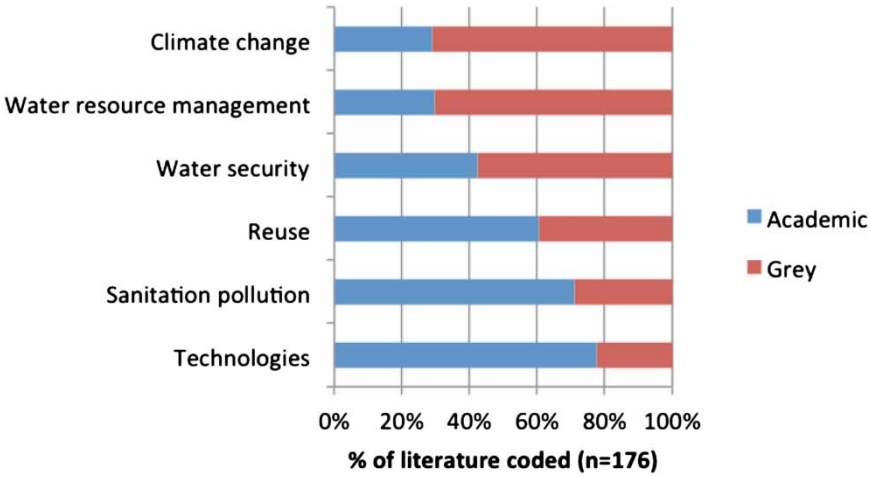

Figure 3 | Proportions of academic and grey literature for common topics.

the in-depth analysis of the 40 most relevant sources: (i) the perceived tension between environmental sustainability and development imperatives; (ii) water security as a potential bridge between service delivery and environmental sustainability; (iii) responding to environmental threats such as climate change; and (iv) water and sanitation services offering opportunities to contribute to environmental sustainability. These themes are interlinked and in some aspects cover related content, yet each offers a distinct perspective on how WASH sector literature engages with concepts of environmental sustainability. Following the analysis of themes, we consider them with reference to the planetary boundaries framework.

Development and environment in tension

Despite 'sustainable development' being a decades-old concept which brings together economic, social and environmental goals with a view to providing for both present and future generations (WCED 1987), economic and social development and environmental sustainability have often been seen as being in competition with each other (Melamed *et al.* 2012; Atkinson *et al.* 2014). Considering

environmental outcomes along with development and poverty reduction has been seen as 'too hard' in situations where simply meeting basic needs is challenging. The time dimension is also important here, with human development an urgent concern and environmental protection often presented as something to be resolved or 'dealt with later'.

The WASH sector reflects this dichotomy, with both the 'too hard' and 'deal with it later' perspectives evident in the reviewed literature. In analysing the role of the environment as a 'silent partner' in Latin-American urban WASH programs, Keatman (2012) observed that environmental considerations were given far less emphasis than issues of finance, technology, equity and poverty alleviation, and were seen as complicating the already significant challenge of improving access. In this context, despite general recognition that environmental protection would benefit upstream and downstream users, it was considered 'something to tackle at a later stage' (Keatman 2012). Similarly, Batchelor *et al.* (2011) described the WASH sector as slow to respond to risks due to the focus on 'more immediate challenges', Mehta & Movik (2014) noted the tendency for those promoting water service delivery to neglect environmental considerations despite recognizing the importance of the natural resource base, and Bradley & Bartram (2013) asserted that for some in the sector, the urgency of household sanitation provision overrides the need for full excreta management.

Factors contributing to the perceived tension between environment and development in the WASH sector and beyond relate to the physical and time scales at which we typically conceive the two. The international development sector has predominantly measured progress with reference to individuals, whereas environmental dynamics are often analysed at global, regional or local (beyond household) scales (Melamed *et al.* 2012). A similar disjunct relates to time, with service delivery a short-term urgent need for current populations, in contrast with often longer-term environmental issues that will most likely affect future generations (Keatman 2012; Melamed *et al.* 2012).

For the WASH sector, it is important to recognize these tensions if we are to better contribute to environmental sustainability through current approaches. There is promise in the renewed SDG agenda, which is substantially broader in scope than its MDG predecessor and includes a number of beyond-household objectives within the integrated water and sanitation goal. This optimism was reflected in the post-2015 consultation on WASH and environmental sustainability, which found that 'the environmental and development communities are gradually superseding their respective misperceptions that WASH and environmental sustainability are unconnected and/or may compete for resources and political attention' (Post-2015 Water Thematic Group 2013). The challenge is to embrace this agenda as a prompt to move beyond our current focus on individuals and their urgent needs, such that realization of the rights to water and sanitation achieves sustainable services for future, as well as current, generations and does not adversely impact ecosystems.

A helpful way of conceptualizing how we can achieve human development and environmental sustainability is offered by Raworth (2012) in her adaptation of the planetary boundaries framework. Raworth (2012) proposed the addition of 'social boundaries', advocating the need to define a 'safe *and just* operating space for humanity' (emphasis added) that accounts for both earth system limits (described as the 'environmental ceiling') and basic human rights (the 'social foundations'). The resulting framework offers a doughnut-shaped 'safe and just space', bounded at the centre by a set of social foundations (Figure 4). Further work is required to develop the social dimensions within this framework, which are at present only illustrative (Raworth 2012, 2013). For the WASH sector, there is an opportunity to develop ideas about how to link the 'safe' and the 'just' at the local level, where the connections are most meaningful for people and the environments that support them.

Water security as a bridge between WASH and environmental sustainability

The second theme relates to the concept of water security. The way water security is defined and discussed in WASH literature is critiqued here, and we consider its potential to bridge service delivery and environmental sustainability goals with reference to limitations apparent from the reviewed material.

In recent years use of the term 'water security' has been increasing in policy and academic circles across the water

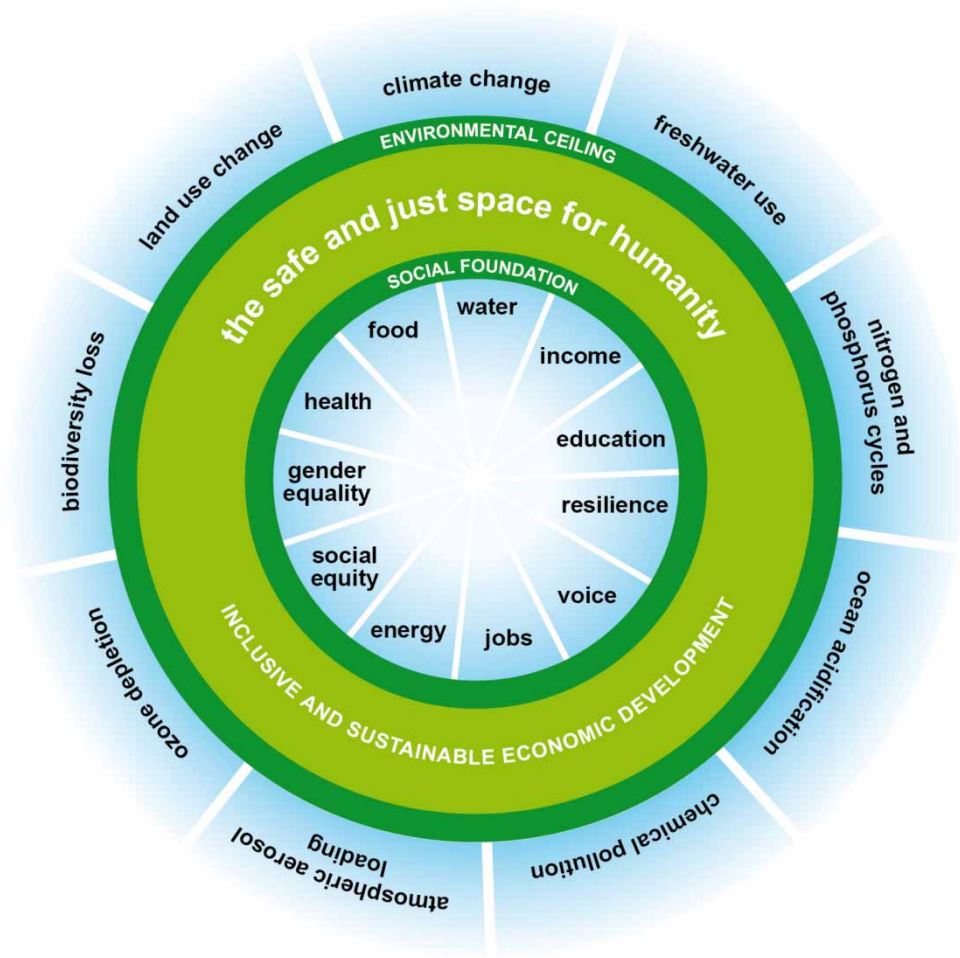

Figure 4 | A safe and just operating space for humanity (Raworth 2012).

sector (Cook & Bakker 2016). In the WASH sector, the term emerged within post-2015 discussions as a conceptual tool to help us move beyond the narrowly focused MDG 'access' agenda towards a broader understanding of service delivery within a wider water management framework (Bradley & Bartram 2013). Many concepts associated with water security are not new, given the close relationship between water security and IWRM. Yet in recent WASH sector literature, water security has attracted more interest than IWRM, perhaps because 'security' terminology conveys a sense of urgency related to water crises and the scale of unmet needs, and therefore has the capacity to raise the issue on the political agenda (Pahl-Wostl *et al.* 2016).

There is no one agreed definition of water security, with interpretations ranging from an emphasis on meeting basic human needs through to incorporation of ecosystem needs (Pahl-Wostl *et al.* 2016). The reviewed WASH literature reflected this, with definitions spanning those emphasizing access to water (e.g. Calow *et al.* 2011) and those encompassing broader livelihood, development and environmental goals (e.g. Chiappe *et al.* 2015). In the latter, water security was presented both as a driver (at the political and practical levels) for integrated approaches to WASH service delivery and water resource management, and as a conceptual tool that can help us find practical ways to implement those approaches. It was seen as useful when considering services at multiple scales, including local contexts on which WASH programs typically focus (Bunclark *et al.* 2011).

An exploration of the potential for the concept of water security to contribute to improved domestic water and

sanitation was provided by Bradley & Bartram (2013), who adopted Grey & Sadoff's (2007) often cited definition of water security as 'the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environment and economics'. Bradley & Bartram (2013) argued that the MDG focus on the household as a unit of analysis diverted attention away from both 'upstream' (water source reliability) and 'downstream' (sanitation pollution) concerns. They asserted that a definition of water security that addresses both *provision* and *risk* offers an opportunity to promote increased access to water and sanitation in a way that encompasses previously neglected areas of critical importance to the sector, including water source management (which requires, among other things, responding to pressures such as climate change) and environmental contamination related to pollution from inadequate sanitation. Importantly, the concept of water security is linked to the human rights to water and sanitation, with Bradley & Bartram (2013) arguing that benefits arising from applying a water security lens to domestic water and sanitation challenges will only arise if 'enlightened by human rights insights'.

In reflecting on the potential of water security to strengthen the links between WASH and environmental sustainability, it is helpful to consider three limitations evident in the reviewed literature. Firstly, there was a common perception that WASH service delivery does not present a threat to water security for people or nature at the global scale. Some studies have argued that physical water scarcity has been overemphasized in the sector (Bunclark *et al.* 2011; Calow *et al.* 2011; Mason & Calow 2012) with scarcity of basic services seen as being more appropriately conceived of as resulting from issues of access, equity and governance (Calow *et al.* 2011). This view derived from the fact that non-domestic sectors such as agriculture account for the vast majority of current freshwater demand (Corcoran *et al.* 2010) and from estimates that the quantity of water required to meet basic water and hygiene is <1% of available freshwater resources in most countries (assuming delivery of 50 litres/capita/day) (Doczi *et al.* 2013).

Yet this calculation neglects the fact that domestic water use in low-income countries already averages 8% of total freshwater removal (UNEP (2007) cited in Rognerud *et al.* (2016)), and the important consideration that the availability of water for domestic consumption depends greatly on the levels of service provided (Doczi *et al.* 2013). Community-scale programs are unlikely to put significant pressure on freshwater resources (except in water scarce environments), but ever-increasing quantities of water delivered to rapidly growing urban populations will, with demand from these populations likely to be significantly higher than 50 litres/capita/day (LCD). For example, in urban contexts recent literature has reported much higher water demand figures of, for example, ~150 LCD in Can Tho, Vietnam (Retamal *et al.* 2011) and ~200 LCD in Port Vila, Vanuatu (Poustie & Deletic 2014). As economic development progresses, it is likely that higher demand will follow (Rognerud *et al.* 2016), given that domestic water consumption in developed countries is approximately six times that in developing countries (Shiklomanov (1999) cited in Corcoran *et al.* (2010)). Compounding the problem is the fact that the collective impacts of increasing water demand on a particular water resource are rarely assessed (Bunclark *et al.* 2011).

A second possible limitation to the potential of water security to bridge service delivery and environmental sustainability is the relatively limited overlap of water security/WASH literature with literature focused on sanitation pollution. While sources focused on water security note risks to water quality and hence water security resulting from poor management of excreta and wastewater (e.g. Bradley & Bartram 2013), 'water security' as a potentially useful concept has yet to strongly enter literature more directly focused on sanitation pollution. Only a small proportion of the sources that focused on sanitation pollution mentioned water security (12%, $n = 7$ of 58). Whether the concept of water security can contribute to improved models of wastewater and excreta management (towards meeting SDG6 targets) is yet to be determined.

The third limitation is that it remains to be seen how the WASH sector's embracing of water security will translate into practical outcomes. To date, literature on water security has tended to focus at a theoretical level, exploring its boundaries and potential but with somewhat limited relevance to policy and practice (Bakker 2012; Mason & Calow 2012). Water security needs to be transformed from an abstract concept into meaningful and practical approaches or tools, but this is a challenging task. It requires

developing ways to measure water security, which is problematic given the spatial and temporal variability inherent to water systems and given that 'indicators are usually only relevant at a particular spatial or temporal scale' (Mason & Calow 2012).

Despite these limitations, the increasing presence of water security as a relevant concept in WASH discourse holds promise in that it reflects a move to encompass both human and environmental water resource management objectives. As we strive to achieve the integration agenda presented by the SDGs there is an opportunity to both draw on and shape ideas about water security to inform environmentally sustainable approaches to service delivery. For this to be effective, we need to promote a sector-wide conception of water security that embraces services for people as well as upstream and downstream concerns.

Responding to environmental threats

Related to concepts of water security, the idea of services being threatened or at risk due to environmental pressures has emerged as a theme within WASH literature. This is relevant to understanding the WASH sector's engagement with environmental sustainability, as the ways we respond to threats and risks will have implications for resources and ecosystems. The focus of the literature was predominantly on climate change and associated threats, though issues of freshwater availability and quality more generally also featured (and are strongly associated with the water security discourse discussed above).

With reference to climate change, the WASH sector was depicted as vulnerable to current climatic variability (Doczi 2013) and under significant threat from climate change impacts – such as changes in rainfall, groundwater recharge and climate extremes – in the medium to longer terms (e.g. Batchelor *et al.* 2011; Calow *et al.* 2011; Heath *et al.* 2012; Doczi 2013; Oates *et al.* 2014). Impacts were presented as well-acknowledged and inevitable, though the location, scale and timing of threats is uncertain (Batchelor *et al.* 2011; Heath *et al.* 2012; Doczi 2013). The literature strongly focused on risks to water systems, and Calow *et al.* (2011) noted an absence of material exploring the specific links between climate change and sanitation. Nevertheless, increasing awareness of vulnerability to climate change across the sector has prompted a proliferation of tools to support adaptation and resilience, though as Doczi (2013) pointed out, many of these are supply-driven and there is little evidence of user demand (for a review of tools see Doczi (2013)).

Of interest in this literature are the types of service delivery and management responses advocated, which fall broadly into two categories: 'climate proofing' and integrated adaptation measures. Each of these has implications for environmental sustainability and for service sustainability, so they are relevant to this discussion.

Literature promoting 'climate-proofing' solutions has presented climate change risks as relevant due to their capacity to disrupt water and/or sanitation services. This framing is reactive, dominated by strategies for fostering more robust and resilient services. Responses advocated have included increasing redundancy in water supply systems by augmenting storage capacities (e.g. Batchelor *et al.* 2011; UNICEF/GWP 2015), adapting technologies to be resilient to climate impacts (Calow *et al.* 2011), and relying more on apparently less vulnerable sources such as deeper groundwater aquifers (Calow *et al.* 2011). Calow *et al.* (2011) noted that in national adaptation plans, supply-side solutions (such as increased water storage) were favoured over demand-side alternatives (such as improved efficiency or more equitable allocation). This aligns with Mehta & Movik's (2014) observation that 'often technology is evoked to solve problems of water scarcity'.

Yet ironically, while these solutions have been proposed in response to environmental pressures, there was little evidence that the environmental implications of suggested technological fixes have been considered. 'Climate proofing' solutions that rely on building bigger, stronger infrastructure will inevitably have flow-on environmental effects including both local (e.g. over-extraction of water) and diffuse (e.g. greenhouse gas, GHG) impacts. One example is that of groundwater, which is promoted by some authors as a potentially more reliable source with capacity to offset increasing scarcity of surface water, despite acknowledgement that groundwater risks from climate change are poorly understood (Bunclark *et al.* 2011; Calow *et al.* 2011) and already 20% of the world's aquifers are over-exploited (WWAP (2015) cited in Rognerud *et al.* (2016)). Potential impacts were given less prominence in a discourse framed around

'solving' environmental problems, but there is opportunity for the WASH sector to take a more nuanced approach, thinking not only about protecting services from threats, but also about how services can either exacerbate or ameliorate environmental pressures.

Some WASH literature takes a more environmentally sensitive approach, asserting that to achieve resilient services we need to embed WASH within resource management, focus on demand-side solutions, and strengthen links between governance of WASH and environment. Hadwen *et al.* (2015) proposed considering WASH within an IWRM approach as a means of bringing together economic efficiency, equity and environmental sustainability goals, noting that WASH has typically focused on equity (services for all) while IWRM has emphasized economic and environmental drivers. Examples of interventions to protect water quality which can both reduce health risks and achieve environmental outcomes include riparian restoration and improved land management practices (Dosskey *et al.* (2010) cited in Hadwen *et al.* (2015)). Demand-side solutions to relieve pressures on water supply systems were proposed by Poustie & Deletic (2014) including rainwater capture, increased water efficiency and demand management. Interestingly, both Hadwen *et al.* (2015) and Poustie & Deletic (2014) focused on Pacific Island countries, which perhaps reflects the more immediate environmental pressures faced by these communities and the consequent need to position WASH within broader environmental sustainability endeavours. A complementary approach was suggested by Batchelor *et al.* (2011) who emphasized the importance of governance reform for effective integration and adaptation. This includes rethinking institutional arrangements to address current constraints associated with environment departments (who typically oversee climate change initiatives) being on the periphery while WASH departments are more central (Batchelor *et al.* 2011).

Common in this literature (across both 'climate proofing' and 'integration' perspectives) is the assertion that to better manage environmental risks and uncertainties, we need improved data and knowledge, with climate change in particular putting a premium on information about water resources (Calow *et al.* 2011; Doczi 2013; Hadwen *et al.* 2015). As Calow *et al.* (2011) assert, 'few countries know about the quantity, quality, distribution and reliability of their water resources, about how they are being used, or which water sources are functional'. To appropriately respond to the threats presented by climate change and other environmental pressures, it will be critical to improve the ways in which we collect and share data to ensure our solutions do not become future environmental problems.

WASH as an environmental opportunity

The fourth theme in the current discourse frames sanitation and water service delivery as presenting opportunities to contribute to environmental sustainability. This literature goes beyond the harm minimization perspective evident in sanitation pollution literature and promotes potential contributions to critical sustainability concerns related to nutrients, energy and water scarcity. Central to this discourse is literature on ecological sanitation, though the potential for WASH to contribute to sound watershed and ecosystem management is also evident (for example Edmond *et al.* 2013). Around 60% of documents coded as reflecting an 'environmental opportunity' theme come from academic sources, which is an interesting contrast to material focused on links between WASH and water security or climate change, of which 60 and 73% respectively are from non-academic sources. This likely reflects the emphasis to date within 'environmental opportunity' literature on theory or pilot-scale programs rather than more widespread practice, as discussed below.

The potential benefits of reusing wastewater and excreta were described as significant for water, food, nutrient and energy security. With reference to water security, the use of wastewater for irrigation is proposed as a solution to increasing water scarcity and competition (Hanjra *et al.* 2012) in a context where 70–90% of global available fresh water is used for agriculture (WWAP (2014) cited in Rognerud *et al.* (2016)). This links to food security, as does literature promoting the potential of using nutrients from sanitation to reduce our dependence on increasingly scarce mineral reserves (Cordell *et al.* 2009; Rosenqvist *et al.* 2016) while simultaneously reducing pollution by preventing the return of nutrients to the environment. Corcoran *et al.* (2010) presented typical nutrient concentrations in effluent, asserting that effluent has the capacity to provide all the nitrogen and much of the phosphorus

and potassium needed for agricultural crop production, in addition to other beneficial micronutrients and organic matter. With reference to energy security, some literature focuses on biogas from human waste as a potential alternative to fossil fuels (e.g. Doczi *et al.* 2013), however this was less prevalent in the reviewed literature.

The benefits of reuse were typically presented with words of caution related to health, behavioural and economic aspects, and these are important areas to consider when exploring how to capitalize on the potential contribution of sanitation and water services to environmental sustainability. As noted by Hanjra *et al.* (2012) frameworks for protecting human health and the environment when planning wastewater reuse are lacking in most developing countries, and many of the potential impacts (such as imbalances in microbiological communities) are not yet well understood. On the behavioural side, proper management and user acceptability (particularly in cultural contexts in which reuse of human waste is taboo) are noted as significant constraints (Kennedy-Walker *et al.* 2014). With reference to economic aspects, the literature is mixed. Some sources pointed to potentially higher costs associated with reuse infrastructure (e.g. Abraham *et al.* 2011), while others asserted that reuse actually presents a value proposition with sales from products such as fecal sludge able to generate profits that could in turn be used to support the sanitation service chain (e.g. Diener *et al.* 2014; Tilmans *et al.* 2014).

Across the literature, two scales of focus were evident: conceptual big-picture material extolling the potential of resource reuse (e.g. Cordell *et al.* 2009; Corcoran *et al.* 2010), and reports of highly localized pilot programs, with little in between. Although reuse has been promoted in the sector for more than 15 years, including through the Bellagio Principles for Urban Environmental Sanitation (SANDEC/WSSCC 2000) and the ecological sanitation 'toolbox' released by GIZ in 2003, the impact of this in driving stronger adoption of 'ecological' technologies in cities is not evident (Kennedy-Walker *et al.* 2014). Similarly, reports from rural areas are often small scale and confined to a few locations, with limited attention given to the potential for more widespread application (e.g. Arafat & Rahman 2010; Abraham *et al.* 2011; Kamuteera 2011; Okem *et al.* 2013). In keeping with ideas from the field of transition studies about the scales at which socio-technical shifts occur (as described in Geels (2011) and Lawhon & Murphy (2012)), current discourse indicates that resource reuse approaches currently operate at the 'niche' (micro) scale and are yet to move into the 'regime' (meso) or 'landscape' (macro) scales that would reflect wider adoption in the sector and society at large. This is discussed further below under future directions.

Nevertheless, the presence of this theme in WASH discourse is promising. If we can identify strategies to support a shift in the practical application of ecological sanitation approaches from the niche level to the landscape scale (including in growing urban centres), then the potential for WASH to contribute to environmental sustainability will be significant. As Bradley & Bartram (2013) assert:

> '*in water and sanitation beneficial use of wastewater and excreta is the great scientific, technological and environmental challenge or opportunity of the coming quarter-century and is of special relevance to poor rapidly developing countries. There are doubts about the economic feasibility of classical sewerage and about its logic: to dilute excreta with precious water and then separate the two again is costly and energy-intensive.*'

FUTURE DIRECTIONS – INSIGHTS FROM A PLANETARY BOUNDARIES PERSPECTIVE

This section considers current themes in WASH discourse with reference to the planetary boundaries framework. The assessment helps us gauge the extent to which our focus as a sector aligns (or not) with a clear set of earth system processes fundamental to environmental sustainability, and prompts us to contemplate what else we could or should be considering. The discussion then proposes four 'future directions', which are areas where opportunities exist for the WASH sector to increase focus and action to strengthen our contribution to environmental sustainability as we ramp up efforts towards progressive realization of the human rights to water and sanitation. Where relevant, reference is also made to SDG6 and its water resource management targets.

Planetary boundaries and themes in reviewed literature

As noted earlier, the planetary boundaries framework offers a useful way of engaging with fundamental socio-ecological

systems and processes that constitute environmental sustainability. The framework is relevant and useful for sustainable development discourse (Griggs *et al.* 2013; Pisano & Berger 2013), but further thinking needs to be done about what it might mean in practice for different sectors, actors and scales. For the WASH sector, there is potential to explore how the planetary boundaries framework might prompt more environmentally sustainable approaches. Five of the nine boundaries are directly affected by flows and processes associated with WASH service delivery, particularly given the dominant paradigm of water-borne sanitation (Ross *et al.* 2015).

Table 1 presents the five planetary boundaries most relevant to WASH and assesses how each of the boundaries is reflected in the reviewed literature. It is important to note that this assessment is preliminary and based on a review of general 'environmental sustainability' literature rather than a detailed analysis of the overlaps between boundaries (with each boundary having its own terminology) and WASH resources, and each could reasonably be the subject of an entire review. Nevertheless, the assessment is helpful for prompting consideration of potential future directions for the sector.

FUTURE DIRECTIONS

Reflecting on both identified themes and their relevance to planetary boundaries, this review concludes by proposing four future directions for strengthening the contribution of

Table 1 | Planetary boundaries, their relevance for WASH and representation in reviewed literature

Planetary boundary	Relevance for WASH services	Reflection in reviewed literature
Global freshwater use	Centrally implicated in water supply (including for hygiene needs) and water-based sanitation. While the global freshwater use boundary remains classified within the 'safe' space, the spatial distribution of freshwater determines varying regional thresholds for safe use (Rockström *et al.* 2009). Many regional water systems are already experiencing scarcity (Gleick & Palaniappan 2010) and it is forecast that by 2050, 40% of the global population will live in areas facing water stress (Rognerud *et al.* 2016)	Reflecting SDG6 targets, emerging literature highlights the need for WASH professionals and communities to better manage water resources at local scales in terms of both upstream and downstream considerations. Concerns about declining freshwater availability and quality were expressed in discussions related to water security and climate change. To date, the emphasis has been on potential risks to WASH services and the need to consider water resources as part of the service delivery landscape, with less focus on practical ways to address emerging challenges related to freshwater availability and quality. Further, potentially important considerations such as efficiency of water use have not received attention
Nitrogen and phosphorus cycles (biochemical flows)	Sanitation presents both a challenge and opportunity for the safe functioning of these biochemical flows. Recent research estimates that sanitation treatment systems in 108 low- and middle-income countries remove only 11% of nitrogen and 17% of phosphorus from human excreta, with the balance discharged into the environment (Fuhrmeister *et al.* 2015) where it contributes to eutrophication of aquatic and marine systems (Rockström *et al.* 2009). Intentional reuse of N and P from excreta has the potential to both reduce this environmental impact and help meet demand for P fertilizers to support food security (and livelihood) needs in the context of increasing scarcity of mineral rock phosphate reserves (Cordell *et al.* 2009)	The potential for sanitation approaches that take account of nitrogen and phosphorus cycles was described in the literature, however the focus was limited to smaller scale local or pilot activities Further, the literature focused on sanitation pollution did not specifically note issues related to nitrogen and phosphorus flows, which is a limitation given low removal rates from current treatment systems

(*continued*)

Table 1 | continued

Planetary boundary	Relevance for WASH services	Reflection in reviewed literature
Climate change	WASH services contribute to climate change through the energy intensity of water and sewage systems (Ross *et al.* 2015). Greenhouse gases including methane are emitted by water reservoirs (Deemer *et al.* 2016), municipal wastewater treatment plants (Campos *et al.* 2016), pit latrines (Reid *et al.* 2014) and septic tanks (Truhlar *et al.* 2016). Recent research in the United States found that GHG emissions from domestic septic tanks account for 1.5% of a person's annual carbon footprint (Truhlar *et al.* 2016)	The risks posed by climate change to WASH services were a significant area of concern in the literature, though a focus on 'climate proofing' approaches has potentially negative consequences. There is opportunity to develop responses that are environmentally sensitive and to more strongly consider the energy intensity and GHG emissions of water and sanitation infrastructure solutions
Novel entities	Novel entities are defined by Steffen *et al.* (2015) as 'new substances, new forms of existing substances, and modified life forms that have the potential for unwanted geophysical and/or biological effects… These potentially include chemicals and other new types of engineered materials or organisms.' Examples are endocrine disruptors and persistent organic pollutants. Novel entities can be added to domestic wastewater through human excreta (e.g. pharmaceuticals) or household chemicals (Kinney *et al.* 2006; Ross *et al.* 2015)	Novel entities were not considered at all in reviewed literature, yet they are relevant to how we approach sanitation services (including treatment and reuse/disposal). This is of particular concern for urban areas with growing middle-income populations, where the use of household chemicals, personal care products and pharmaceuticals is increasing
Biosphere integrity	Over-extraction of water and inadequate sanitation threaten freshwater and coastal ecosystems (Gleick 2003; Corcoran *et al.* 2010)	There was limited explicit discussion in reviewed literature on water-related ecosystems. Freshwater ecosystems were noted to be beneficiaries of improved sanitation, but drivers were more often related to the availability of freshwater for human consumption than ecosystem integrity

the WASH sector to environmental sustainability:

1. Foster a 'do more good' instead of 'do less harm' approach
2. Focus on synergies and minimize trade-offs
3. Identify and address gaps in current focus
4. Support a transition of the reuse agenda from niche to regime scale.

Each of these is explained and we propose ideas on starting points for the WASH sector. Suggestions are primarily directed at knowledge leaders (within international WASH sector organizations) and researchers rather than practitioners, acknowledging that translating ideas into meaningful on-the-ground actions will take thought and time. The intention is to flag the need for research and prompt creative thinking to inform these future directions in WASH.

Do more good instead of do less harm

The idea of fostering a 'do more good' instead of a 'do less harm' approach is implicit within the planetary boundaries framework. It dictates that we move beyond governance and management approaches based on limits to growth and minimizing negative externalities (Rockström *et al.* 2009), towards cross-sectoral consideration of strategies for remaining within a safe space for human development. The related imperative to 'do more good' (in contrast to simply minimizing negative impacts) has been advocated by McDonough & Braungart (2002), cited in Corcoran *et al.* (2010), with reference to cradle to cradle production systems, and by Mitchell (2015) with reference to infrastructure.

There is no blueprint for what this kind of approach might look like. There is an opportunity to start thinking in this way to prompt the development of new decision-making processes and metrics (Mitchell 2015). For the

WASH sector, this will require carefully defining our objectives to include both access and environmental considerations, and remembering that *how* goals are achieved matters as much whether they are achieved. There are links here to water security and reuse agendas. Ecosystems (and the resources they support) can benefit from WASH programs that explicitly consider upstream and downstream dynamics, and undertaking freshwater conservation and WASH together can foster environmental stewardship (Edmond *et al.* 2013). Using nutrients extracted from human waste as an alternative to commercial fertilizers has positive flow-on effects for water quality (by reducing pollution), food security and mineral resource scarcity (Cordell *et al.* 2009).

Maximize synergies and minimize trade-offs

Related to the idea of 'doing more good', the second recommendation calls for a shift in mindset and approaches towards emphasizing synergies and minimizing trade-offs. This recognizes the interdependence of earth systems, as transgressing one planetary boundary will shift others (Rockström *et al.* 2009), and this reflects the interconnectedness of the SDGs. Ignoring the overlaps between SDGs and focusing on meeting individual targets risks perverse outcomes (Nilsson *et al.* 2016). For example, increasing food production will likely increase diffuse water pollution which can negatively impact on water quality targets (Doczi *et al.* 2013). However, conversely, as Nilsson *et al.* (2016) assert, if 'mutually reinforcing actions are taken and trade-offs minimized, the agenda will be able to deliver on its potential'. There are numerous examples of potential synergies within the SDGs (as described by Nilsson *et al.* (2016)) and the interdependencies between water goals and goals related to energy, food security and natural resource management are well recognized (Merrey *et al.* 2015).

For the WASH sector, this thinking drives us in two directions. Firstly, we need to ensure that in striving to achieve water and sanitation access targets (6.1 and 6.2) we do not inadvertently undermine the achievement of related water resource management targets (6.3–6.6) or other SDGs with explicit environmental sustainability agendas (such as clean energy, sustainable cities and communities, climate action, life below water, and life on the land). This requires considering interconnections when designing our approaches. For example, sanitation solutions need to align with locally available water resources, so flush toilets might not be a preferable option in certain locations, even if this is the option desired by users. User preferences are a critical consideration, but resource availability is equally important. Another example is the need to account for energy requirements and GHG emissions associated with infrastructure solutions. This thinking can lead to further benefits. For example, designing systems that require less pumping and therefore have lower energy demands can result in significant cost savings over the life-cycle of water supply or sanitation systems (e.g. Willetts *et al.* 2010).

Secondly, we need a shift in mindset away from considering environmental sustainability as too hard or not urgent (as discussed above) towards thinking creatively about potential win-wins and how to capitalize on them. Many synergies between service delivery and environmental sustainability are evident in concepts such as integrated urban water management (e.g. Bahri 2012) and the water-energy-food nexus (e.g. Weitz *et al.* 2014; Bhaduri *et al.* 2015). There is also potential for multiple-use water systems to bring benefits across service delivery, food security and livelihoods. However, support for environmental sustainability efforts is also needed to better integrate resource and climate resilience into current approaches (Srinivasan *et al.* 2012). Finally, opportunities exist to integrate environmental sustainability into our advocacy of the human rights to water and sanitation. These rights include the obligation to provide services in a way that respects the environment and protects resources from overexploitation or pollution in order to ensure their availability for future generations (UN Special Rapporteur 2014). While acknowledging the magnitude of the challenge of getting basic services to those currently without them, approaching this task by seeking to maximize synergies between service delivery and environmental sustainability may prompt new thinking towards mutually beneficial outcomes.

Identify and address key gaps

Consideration of both planetary boundaries and the SDG targets reveals gaps in WASH sector considerations related to environmental sustainability, for example in areas of

climate change mitigation, novel entities, biosphere integrity and water use efficiency (as a key component of freshwater management). Here, attention is given to novel entities and water use efficiency as examples.

The presence of novel entities in water sources and wastewater is an area of concern in water sector literature globally, and particular risks for developing country contexts have been noted due to weaker regulatory frameworks (Tijani *et al.* 2013). Micro-pollutants relevant to domestic contexts derive from pharmaceuticals, personal care products and household chemicals, with the use of these increasing as populations and wealth grow (particularly in urban areas). These contaminants are not always or easily biodegradable and their effects are poorly understood. However, serious negative impacts on ecosystem and public health have been documented, including endocrine disruption, brain damage, cancer and reproductive disorders (Tijani *et al.* 2013). As the WASH sector progresses initiatives to improve wastewater treatment and excreta management, we need to acknowledge the presence of novel entities and consider potential responses – including, for example behaviour change programs which include strategies for reducing their discharge, working with governments to strengthen regulations, and keeping abreast of advances in treatment approaches that may be applicable to developing country contexts.

Water use efficiency is another area of opportunity currently neglected within WASH sector literature that can contribute to sustainable management of freshwater resources. SDG6 target 6.4 calls for a substantial increase in water-use efficiency, with proposed indicators collating efficiency improvements across significant water-using sectors including municipal water supply (IAEG-SDGs 2015). The proposed measure relates to unaccounted for water (network losses), and WASH initiatives can both contribute on this front and go beyond to also consider the promotion of water efficient technologies and behavioural strategies for enhancing water use efficiency through demand management, particularly in urban areas. This is an area in which significant work has been done by the wider water sector (e.g. Butler & Memon 2006; Araral & Wang 2013; Bao *et al.* 2013) that can inform WASH sector initiatives, particularly as per capita consumption rates rise and local experiences of water scarcity become more common. Increasing the focus on water efficiency is also relevant for water abundant areas, as managing demand achieves reductions in energy use and costs related to transport and treatment.

Support a transition of the reuse agenda from niche to regime

A final future direction is about supporting the transition of wastewater/excreta reuse initiatives from local to wider scales to capitalize on the environmental and food security opportunities presented by such approaches. For these initiatives (and for other changes we seek to make) it is appropriate to draw on ideas from transition studies and transition management literature. Transition studies is an emerging field that brings together insights from complexity science, innovation studies, sociology and environmental science to better understand and develop strategies for influencing the direction and pace of systemic change in societies (Loorbach *et al.* 2015). As described above, it characterizes a typical trajectory of socio-technical shifts from niche to regime and ultimately landscape scales (Geels 2011; Lawhon & Murphy 2012). Niche scales are areas of innovation and learning often operating independently of regime dynamics (Geels 2011). The regime level refers to established systems, practices, values, habits and institutional structures (Geels 2011). The institutions at this level play normative and regulatory roles and in doing so offer stability, but can limit innovation to incremental improvements (Geels (2005) cited in Haxeltine *et al.* (2008)).

For the WASH sector, conceptualizing reuse opportunities in this way may assist in ultimately moving them beyond niche experimental scales towards wider uptake. This requires reframing reuse as a necessary transition towards sustainability and positioning pilot initiatives (whether successful or not) within this transition, acknowledging that the path of change might be slow and challenging. It also requires targeting investment and research towards reuse with a view to enabling wider and longer-term uptake, for example by further developing strategies for minimizing health risks and investigating emerging concerns such as the presence of novel entities in excreta and wastewater.

Two ideas from transition management could inform this shift. The first is co-evolution, which recognizes that

processes in technology, economy and society progressively build towards systemic change in the long term (Loorbach *et al.* 2015). For reuse programs, this creates a need to engage and align with the regime institutions that steer economic and social processes to maximize the impact of niche-level innovation, for example by working closely with governments at multiple levels to generate the social learning essential for transitions to succeed (Loorbach *et al.* 2015).

The second idea refers to 'tipping innovation's cascade' and involves prioritizing actions that can trigger larger changes (Loorbach *et al.* 2015). In developing countries, investing in technologies and social programs that support reuse can avoid path dependencies that limit innovation and potentially trigger 'technological leapfrogging' as has been seen in industries such as telecommunications but not yet in water (Poustie & Deletic 2014). The challenge for the WASH sector is to identify opportunities that progress innovation without compromising on core health and social outcomes. The barriers are many and the pathways are not always clear, but increasing risks to global sustainability as demonstrated by the planetary boundaries framework are a clear reminder of the need to try.

CONCLUSIONS

The significant challenge for the WASH sector in coming decades is to continue to promote safe, equitable service delivery for those living without, while not transgressing planetary boundaries or embarking on a path that will do so in the future. The ways we conceptualize and act on environmental sustainability will determine our success in this respect, including our capacity to achieve the integration agenda prompted by the SDGs. Taking stock of current WASH approaches to environmental sustainability, this paper reviewed recent literature at the intersection of WASH and environmental sustainability, identifying and discussing four themes: a perceived tension between environmental sustainability and WASH development imperatives; the idea that water security is a helpful concept for bridging service delivery and environmental sustainability; different attitudes about how best to respond to threats such as climate change; and promotion of the opportunities offered by WASH to contribute to environmental sustainability.

Themes from recent literature were considered with reference to the planetary boundaries framework as a comprehensive and helpful lens for grounding the socio-ecological systems and processes that constitute environmental sustainability. From this analysis, we proposed four future directions to strengthen the WASH sector's focus on and contribution to environmental sustainability: fostering a 'do more good' instead of 'do less harm' approach; focusing on synergies and minimizing trade-offs; identifying and addressing gaps in current focus; and supporting a transition of the reuse agenda from niche to regime scale. In proposing these future directions, the intention is to encourage researchers and knowledge institutions to adopt more ambitious and creative service delivery approaches that better integrate access and environmental sustainability imperatives.

REFERENCES

Abraham, B., Kakumbi, G. M., Alam, M. & von Muench, E. 2011 Alternative solutions for challenging environments : a look at UNICEF-assisted ecosan projects worldwide. In: *The Future of Water, Sanitation and Hygiene: Innovation, Adaptation and Engagement in a Changing World, 35th WEDC International Conference*, Loughborough, UK, July 6–8, 2011.

Arafat, I. & Rahman, Z. 2010 Ecosanitation: importance and experience from Bangladesh. In: *Proceedings Regional Conference on Appropriate Water Supply, Sanitation and Hygiene (WASH) Solutions for Informal Settlements and Marginalized Communities*, Kathmandu, Nepal, May 19–21, 2010.

Araral, E. & Wang, Y. 2013 Water demand management: review of literature and comparison in South-East Asia. *Int. J. Water Resour. Dev.* **29** (3), 434–450.

Atkinson, G., Dietz, S., Neumayer, E. & Agarwala, M. (eds) 2014 *Handbook of Sustainable Development*. Edward Elgar Publishing Limited, Cheltenham, UK.

Bahri, A. 2012 *Integrated Urban Water Management. Global Water Partnership Technical Committee (TEC) Background Paper 16*. Available from: www.monroban.org/public/documents/outils/uploaded/lts46ngv.pdf (accessed 8 July 2016).

Bakker, K. 2012 Water security: research challenges and opportunities. *Science* **337**, 914–915.

Bao, P. N., Aramaki, T., Otaki, M. & Otaki, Y. 2013 Water demand management: a strategic approach towards a sustainable urban water system in Hanoi. *J. Water Environ. Technol.* **11** (5), 403–418.

Batchelor, C., Smits, S. & James, A. J. 2011 *Adaptation of WASH Services Delivery to Climate Change and other Sources of Risk and Uncertainty. (Thematic Overview Paper 24)*. IRC International Water and Sanitation Centre, The Hague. Available from: www.irc.nl/top24 (accessed 25 May 2016).

Bhaduri, A., Ringler, C., Dombrowski, I., Mohtar, R. & Scheumann, W. 2015 Sustainability in the water–energy–food nexus. *Water Int.* **40** (5–6), 723–732.

Bradley, D. J. & Bartram, J. K. 2013 Domestic water and sanitation as water security: monitoring, concepts and strategy. *Philos. Trans. A Math. Phys. Eng. Sci.* **371** (2002), 20120420.

Brooks, D. & Brandes, O. 2011 Why a water soft path, why now and what then? *Int. J. Water Resour. Dev.* **27** (2), 315–344.

Bunclark, L., Carter, R., Casey, V., Day, St. J. & Guthrie, D. 2011 *Managing Water Locally*. The Institution of Civil Engineers, Oxfam GB, and WaterAid, UK, p. 96.

Butler, D. & Memon, F. A. (eds) 2006 *Water Demand Management*. IWA Publishing, London.

Calow, R., Bonsor, H., Jones, L., Meally, S. O., Macdonald, A. & Kaur, N. 2011 *Climate Change, Water Resources and WASH: A Scoping Study. Working Paper 337*. British Geological Survey, London, p. 59.

Campos, J. L., Valenzuela-Heredia, D., Pedrouso, A., Val Del Río, A., Belmonte, M. & Mosquera-Corral, A. 2016 Greenhouse gases emissions from wastewater treatment plants: minimization, treatment, and prevention. *J. Chem.* 2016. http://doi.org/10.1155/2016/3796352.

Chiappe, F., Mujica, A., Ross, I. & Savage, M. 2015 *Climate Finance and Water Security: Inception Report*. Oxford Policy Management, Oxford, UK.

Cook, C. & Bakker, K. 2016 Water security: critical analysis of emerging trends and definitions. In: *Handbook on Water Security* (C. Pahl-Wostl, J. Gupta & A. Bhaduri, eds). Edward Elgar, Cheltenham, UK, pp. 19–37.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D. & Savelli, H. 2010 *Sick Water? The Central Role of Wastewater Management in Sustainable Development. Water*. United Nations Environment Programme. Available from: http://doi.org/10.1007/s10230-011-0140-x.

Cordell, D., Drangert, J. O. & White, S. 2009 The story of phosphorus: global food security and food for thought. *Glob. Environ. Change* **19** (2), 292–305.

Deemer, B. R., Harrison, J. A., Li, S., Beaulieu, J. J., DelSontro, T., Barros, N., Bezerra-Neto, J. F., Powers, S. M., dos Santos, M. A. & Vonk, J. A. 2016 Greenhouse gas emissions from reservoir water surfaces: a new global synthesis. *BioScience* **66** (11), 949–964.

Diener, S., Semiyaga, S., Niwagaba, C. B., Muspratt, A. M., Gning, J. B., Mbéguéré, M., Ennin, J. E., Zurbrugg, C. & Strande, L. 2014 A value proposition: resource recovery from faecal sludge – Can it be the driver for improved sanitation? *Resour. Conserv. Recycl.* **88**, 32–38.

Doczi, J. 2013 *Climate Risk Management Tools for the Water, Sanitation and Hygiene Sector*. Overseas Development Institute, London, p. 60.

Doczi, J., Dorr, T., Mason, N. & Scott, A. 2013 *The Post-2015 Delivery of Universal and Sustainable Access to Infrastructure Services. ODI Working Paper*. Overseas Development Institute, London, p. 67.

Dosskey, M. G., Vidon, P., Gurwick, N. P., Allan, C. J., Duval, T. P. & Lowrance, R. 2010 The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams. *Journal of the American Water Resources Association* **46**, 261–277. doi:10.1111/j.1752-1688.2010.00419.x.

Edmond, J., Sorto, C., Davidson, S., Sauer, J., Warner, D., Dettman, M. & Platt, J. 2013 *Freshwater Conservation and WASH Integration Guidelines: A Framework for Implementation in Sub-Saharan Africa*. Africa Biodiversity Collaborative Group, Conservation International, and The Nature Conservancy, Washington, DC, USA.

Fuhrmeister, E. R., Schwab, K. J. & Julian, T. R. 2015 Estimates of nitrogen, phosphorus, biochemical oxygen demand, and fecal coliforms entering the environment due to inadequate sanitation treatment technologies in 108 low and middle income countries. *Environ. Sci. Technol.* **49** (19), 11604–11611. http://doi.org/10.1021/acs.est.5b02919.

Geels, F. W. 2005 *Technological Transitions and System Innovations: A Co-evolutionary and Socio-Technical Analysis*. Edward Elgar, Cheltenham.

Geels, F. W. 2011 The multi-level perspective on sustainability transitions: responses to seven criticisms. *Environ. Innov. Soc. Transit.* **1** (1), 24–40.

Gleick, P. H. 2003 Global freshwater resources: soft-path solutions for the 21st century. *Science (NY)* **302** (5650), 1524–1528.

Gleick, P. H. & Palaniappan, M. 2010 Peak water limits to freshwater withdrawal and use. *Proc. Natl Acad. Sci. USA* **107** (25), 11155–11162.

Grey, D. & Sadoff, C. W. 2007 Sink or Swim? Water security for growth and development. *Water Policy* **9** (6), 545–571.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N. & Noble, I. 2013 Policy: sustainable development goals for people and planet. *Nature* **495** (7441), 305–307.

Hadwen, W. L., Powell, B., MacDonald, M. C., Elliott, M., Chan, T., Gernjak, W. & Aalbersberg, W. G. L. 2015 Putting WASH in the water cycle: climate change, water resources and the future of water, sanitation and hygiene challenges in Pacific Island Countries. *J. Water Sanit. Hyg. Dev.* **5** (2), 183–191.

Hajer, M., Nilsson, M., Raworth, K., Bakker, P., Berkhout, F., de Boer, Y., Rockström, J., Ludwig, K. & Kok, M. 2015 Beyond cockpit-ism: four insights to enhance the transformative potential of the sustainable development goals. *Sustainability (Switzerland)* **7** (2), 1651–1660.

Hanjra, M. A., Blackwell, J., Carr, G., Zhang, F. & Jackson, T. M. 2012 Wastewater irrigation and environmental health: implications for water governance and public policy. *Int. J. Hyg. Environ. Health* **215** (3), 255–269.

Haxeltine, A., Whitmarsh, L., Bergman, N., Rotmans, J., Schilperoord, M. & Köhler, J. 2008 A conceptual framework

for transition modelling. *Int. J. Innov. Sustain. Dev.* **3** (1–2), 93–114.

Heath, T. T., Parker, A. H. & Weatherhead, E. K. 2012 Testing a rapid climate change adaptation assessment for water and sanitation providers in informal settlements in three cities in sub-Saharan Africa. *Environ. Urban* **24** (2), 619–637.

Inter-Agency and Expert Group on Sustainable Development Goals Indicators (IAEG-SDGs) 2015 *Compilation of Metadata Received on Indicators for Global Monitoring of the Sustainable Development Goals and Targets. IAEG-SDGs*. Available from: http://unstats.un.org/sdgs/files/Metadata Compilation for SDG Indicators 23 October 2015 Update.pdf (accessed 30 June 2016).

Kamuteera, E. 2011 Promoting ecological sanitation: sharing NKKD WATSAN experiences. In: *35th WEDC International Conference*, Loughborough, UK, pp. 1–4.

Keatman, T. 2012 *The Silent Partner: The Role of the Environment in Multi-stakeholder Partnerships for Urban and Peri-urban Water and Sanitation Supply*. Building Partnerships for Development in Water & Sanitation, London, UK, p. 104.

Kennedy-Walker, R., Evans, B., Amezaga, J. & Paterson, C. 2014 Challenges for the future of urban sanitation planning: critical analysis of John Kalbermatten's influence. *J. Water Sanit. Hyg. Dev.* **4** (1), 1–14.

Kinney, C. A., Furlong, E. T., Zaugg, S. D., Burkhard, M. R., Werner, S. L., Cahill, J. D. & Jorgensen, G. R. 2006 Survey of organic wastewater contaminants in biosolids destined for land application. *Environ. Sci. Technol.* **40** (23), 7207–7215.

Lawhon, M. & Murphy, J. T. 2012 Socio-technical regimes and sustainability transitions: insights from political ecology. *Prog. Hum. Geogr.* **36** (3), 354–378.

Loorbach, D., Frantzeskaki, N. & Huffenreuter, R. L. 2015 Transition management: taking stock from governance experimentation. *J. Corp. Citizenship* **58**, 48–66.

Mason, N. & Calow, R. 2012 *Water Security: From Abstract Concept to Meaningful Metrics: An Initial Overview of Options. Working Paper 357*. Overseas Development Institute, London, UK.

McDonough, W. & Braungart, M. 2002 *Cradle to Cradle: Remaking the Way We Make Things*, North Point Press.

Mehta, L. & Movik, S. 2014 Liquid dynamics: challenges for sustainability in the water domain. *Wiley Interdiscip. Rev. Water* **1** (4), 369–384.

Melamed, C., Scott, A. & Mitchell, T. 2012 *Separated at Birth, Reunited in Rio? A Roadmap to Bring Environment and Development Back Together*, Background Note May 2012. Overseas Development Institute, London, UK.

Merrey, D., Awulachew, S. B., Saruchera, D. & Lautze, J. 2015 *The Critical Role of Water in Achieving the Sustainable Development Goals: Synthesis of Knowledge and Recommendations for Effective Framing, Monitoring, and Capacity Development Paper (draft)*. Paper prepared for: United Nations Department of Economic and Social Affairs.

Mitchell, C. 2015 Liveability? Resilience? Or something more? What ought we expect from the infrastructure of the future? *Water* **21**, 12.

Morelli, J. 2011 Environmental sustainability: a definition for environmental professionals. *J. Environ. Sustain.* **1** (1), 1–27.

Nilsson, M., Griggs, D. & Visbeck, M. 2016 Map the interactions between sustainable development goals. *Nature* **534**, 320–322.

Oates, N., Ross, I., Calow, R., Carter, R. & Doczi, J. 2014 *Adaptation to Climate Change in Water, Sanitation and Hygiene: Assessing Risks, Appraising Options in Africa*. Overseas Development Institute, London, UK, p. 82.

Okem, A. E., Xulu, S., Tilley, E., Buckley, C. & Roma, E. 2013 Assessing perceptions and willingness to use urine in agriculture: a case study from rural areas of eThekwini municipality, South Africa. *J. Water Sanit. Hyg. Dev.* **3** (4), 582–591.

Onwuegbuzie, A. J. & Frels, R. K. 2014 A framework for using discourse analysis for the review of the literature in counseling research. *Counsel. Outcome Res. Eval.* **5** (1), 52–63.

Onwuegbuzie, A., Leech, N. & Collins, K. 2012 Qualitative analysis techniques for the review of the literature. *Qual. Rep.* **17** (56), 1–28.

Pahl-Wostl, C., Gupta, J. & Bhaduri, A. 2016 Water security: a popular but contested concept. In: *Handbook on Water Security* (C. Pahl-Wostl, J. Gupta & A. Bhaduri, eds). Edward Elgar, Cheltenham, UK, pp. 1–18.

Phillips, N. & Hardy, C. 2002 *Discourse analysis: Investigating processes of social construction*. Thousand Oaks, CA: Sage.

Pisano, U. & Berger, G. 2013 *Planetary Boundaries for SD. From an International Perspective to National Applications. European Sustainable Development Network Quarterly Report No. 30.* European Sustainable Development Network, Vienna, Austria.

Post-2015 Water Thematic Group 2013 *WASH and Environmental Sustainability Framing Paper: Integration for Sustainable Development*. Available from: www.unwater.org/downloads/worldwewant/WASH-4-EnvSust-Framing-Paper%20.pdf (accessed 10 June 2016).

Poustie, M. S. & Deletic, A. 2014 Modeling integrated urban water systems in developing countries: case study of Port Vila, Vanuatu. *Ambio* **43** (8), 1093–1111.

Raworth, K. 2012 *A Safe and Just Space for Humanity: Can we Live Within the Doughnut? Oxfam Discussion Paper*, February 2012. Available from: www.oxfam.org/en/research/safe-and-just-space-humanity (accessed 28 September 2015).

Raworth, K. 2013 Defining a safe and just space for humanity. In: *State of the World 2013: Is Sustainability Still Possible?* Island Press/Center for Resource Economics, Washington, DC. pp. 28–38. Available from: http://doi.org/10.5822/978-1-61091-458-1 (accessed 30 June 2016).

Reid, M. C., Guan, K., Wagner, F. & Mauzerall, D. L. 2014 Global methane emissions from pit latrines. *Environ. Sci. Technol.* **48** (15), 8727–8734.

Retamal, M. L., Nam, N. D. G., Willetts, J. R., Mitchell, C. A. & Carrard, N. R. 2011 Comparing household water end-use data from Vietnam and Australia: implications for water and wastewater planning. In: *Proceedings from Efficient 11 – 6th IWA Specialist Conference on Efficient Use and Management of Water*, ed. International Water Association, International Water Association, London, UK, pp. 1–12, 29 March–2 April 2011.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E., Lenton, T., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., De Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. & Foley, J. 2009 Planetary boundaries: exploring the safe operating space for humanity. *Ecol. Soc.* **14** (2), 32.

Rognerud, I., Fonseca, C., van der Kerk, A. & Moriarty, P. 2016 *IRC Trends Analysis, 2016–2025*. IRC, The Netherlands.

Rosenqvist, T., Mitchell, C. & Willetts, J. 2016 A short history of how we think and talk about sanitation services and why it matters. *J. Water Sanit. Hyg. Dev.* **6** (2), 298–312.

Ross, K., Abeysuriya, K. & Mitchell, C. 2015 Developing principle-based targets and indicators for the SDGs. In: *Paper Presented at the 2015 International Conference on Sustainable Development*, Columbia University, New York City, September 23–24, 2015.

SANDEC/WSSCC 2000 Environmental Sanitation in the 21st Century; Summary Report of Bellagio Expert Consultation 1-4 February. SANDEC, Duebendorf.

Shiklomanov, I. 1999 World water resources and their use. A joint SHI, UNESCO project. http://hydrologie.org/DON/html/ (verified 27 March 2017).

Srinivasan, V., Palaniappan, M., Akudago, J., Cohen, M. & Christian-Smith, J. 2012 *Multiple-Use Water Services (MUS): Recommendations for a Robust and Sustainable Approach Multiple-Use Water Services (MUS): Recommendations for a Robust and Sustainable Approach about the Pacific Institute*. The Pacific Institute, Oakland, California.

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B. & Sörlin, S. 2015 Planetary boundaries: guiding human development on a changing planet. *Science* **347** (6223), 1259855.

Tijani, J. O., Fatoba, O. O. & Petrik, L. F. 2013 A review of pharmaceuticals and endocrine-disrupting compounds: sources, effects, removal, and detections. *Water Air Soil Pollut.* **224** (11), 1–29.

Tilmans, S., Diaz-Hernandez, A., Nyman, E. & Davis, J. 2014 The potential for financing small-scale wastewater treatment through resource recovery: experience from Bocas del Toro, Panama. *J. Water Sanit. Hyg. Dev.* **4** (3), 449–459.

Truhlar, A. M., Rahm, B. G., Brooks, R. A., Nadeau, S. A., Makarsky, E. T. & Walter, M. T. 2016 Greenhouse gas emissions from septic systems in New York State. *J. Environ. Qual.* **45**, 1153–1160.

UNICEF/GWP (Global Water Partnership) 2015 *WASH Climate Resilient Development: Integrating Climate Resilience into National WASH Strategies and Plans*. Available from: http://doi.org/http://www.unicef.org/wash/files/Strategic_Framework_WEB.PDF.

United Nations Environment Programme (UNEP) 2007 *Global Environment Outlook: Environment for Development (GEO4)*. United Nations Environment Programme, Nairobi, Kenya.

United Nations 2015 *Transforming our World: The 2030 Agenda for Sustainable Development*. Available from: https://sustainabledevelopment.un.org/content/documents/7891Transforming%20Our%20World.pdf.

UN Special Rapporteur on the human right to safe drinking water and sanitation 2014 *Realising the Human Rights to Water and Sanitation: A Handbook by the UN Special Rapporteur Catarina de Albuquerque*. Available from: www.righttowater.info/handbook/ (accessed 5 July 2016).

World Water Assessment Programme (WWAP) 2014 *The United Nations world water development report 2014: Water and energy*. UNESCO, Paris.

World Water Assessment Programme (WWAP) 2015 *The United Nations world water development report 2015: Water for a sustainable world*. UNESCO, Paris.

WCED (World Commission on Environment and Development) 1987 *Our Common Future: Report of the World Commission on Environment and Development*. United Nations. Oxford University Press, Oxford.

Weitz, N., Nilsson, M. & Davis, M. 2014 A Nexus approach to the post-2015 agenda: formulating integrated water, energy, and food SDGs. *SAIS Rev. Int. Aff.* **34** (2), 37–50.

WHO/UNICEF 2015 *Progress on Sanitation and Drinking Water – 2015 Update and MDG Assessment*. WHO, New York, NY, USA. Available from: www.wssinfo.org/fileadmin/user_upload/resources/JMP-Update-report-2015_English.pdf (accessed 30 September 2015).

Willetts, J. R., Carrard, N. R., Retamal, M. L., Nam, N. D. G., Paddon, M., Thuy, D. X., Trung, N. H. & Mitchell, C. A. 2010 *Selecting Sanitation Options: A Case Study of South Can Tho – Technical Report. Cost Effectiveness and Sustainability of Sanitation Options: A Case Study of South Can Tho – Technical Report*, Institute for Sustainable Futures, University of Technology, Sydney, p. 50.

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