Abstract

In this paper we outline different theoretical approaches, namely outcome vulnerability, contextual vulnerability, and resilience, for addressing climate change effects in the context of water, sanitation, and hygiene (WASH) services. We analysed how these three approaches were employed in the WASH-climate change nexus literature, and discuss the implications for WASH research, policy, and development work. Our analysis of 33 scholarly WASH-climate change nexus papers found that they implicitly draw most frequently on an outcome vulnerability approach that tended to focus on the impact of projected climate change hazards on physical aspects of WASH service delivery. Each individual approach has limitations due to their disciplinary and epistemological foundations and the WASH sector in particular must be mindful of who stands to benefit most and what values will be upheld when these approaches are used. We argue that in most cases it will be beneficial to draw on all approaches and describe challenges and opportunities for integrating different perspectives on preparing for climate change within the WASH sector.

Keywords: climate change; perspectives; resilience; theory; vulnerability; WASH

Introduction

Climate change has already impacted natural and humans systems on all continents of the world and will continue to for the foreseeable future (IPCC 2014a). With respect to water, sanitation, and hygiene (WASH) services, climate change has significant potential to exacerbate water stress and insecurity, increase incidences of water-transmitted infectious diseases, slow or reverse progress of improved WASH coverage, exacerbate inequalities, and undermine achievement of related Sustainable Development Goal (SDG) targets and human rights (Howard *et al.* 2010; Braks & de Roda Husman 2013; Hutton & Chase 2016; OHCHR n.d.). To this end, the WASH sector is increasingly giving attention to reducing the vulnerability or enhancing the resilience of WASH services to climate change in research, policy, and development work.

The purpose of this paper is to critically review the theoretical approaches underpinning existing scholarly WASH literature that focuses on impacts of and adaptations to climate change, and to contribute much needed discussion on conceptualisations of climate change vulnerability and resilience in the context of WASH. The WASH sector has not yet adequately addressed how it should, on a normative level, deal with the threat of climate change. Whether consciously considered or not, all recommended and enacted adaptation actions are based on assumptions which must be examined to fully appreciate their consequences. Further, the general climate change resilience and vulnerability literature offers substantial theoretical discussion and practical experiences that could usefully inform the WASH sector. We seek to fill these gaps by starting a discussion on the implications of how the WASH sector conceptualises how climate change affects WASH services. It also makes propositions, drawing on lessons from the general climate change literature, about how the WASH sector should proceed

The body of this paper is structured into three main sections. The first section provides an overview of prominent theories of vulnerability and resilience as conceptualised in the general climate and global environmental change literature. The second section reviews

scholarly WASH literature that has a climate change focus and categorises the papers by their theoretical approach. In the third section we discuss the implications of differing interpretations of key climate change concepts for the WASH sector and argue that there is a need for improved conceptual awareness in the sector.

Climate change vulnerability and resilience

Vulnerability and resilience have emerged as central concepts in the climate and wider global environmental change literature (Janssen & Ostrom 2006). Within the following sub-sections, we present a high-level overview of key vulnerability and resilience theories and concepts. It is noteworthy that, in practice, approaches often draw on multiple theories simultaneously as currently recommended by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2014a), but we present them here discretely for simplicity. Conceptualisations of vulnerability and resilience go by varying names in the literature, and may be categorised differently, but the terminology and approaches we describe here are largely consistent with the latest thinking on responding to climate change (IPCC 2014a, b) It is not within the scope of this paper to give a comprehensive and detailed review of vulnerability and resilience theories and their histories. For more detailed reviews, we refer readers to Adger (2006), Folke (2006), Folke *et al*. (2010), Füssel & Klein (2006), Gallopín (2006), Miller *et al.* (2010), and Smit & Wandel (2006).

Outcome vulnerability

An early conceptualisation of climate change vulnerability focuses on an evaluation of climate impacts on society and nature, and how these impacts could be offset by adaptation actions (Füssel & Klein 2006). This conceptualisation may be referred to as 'outcome vulnerability' (O'Brien *et al.* 2007). When viewed this way, vulnerability is a function of a system's (e.g. a human, environmental, or coupled human-environmental system of any size at any scale) exposure and sensitivity to *future* hazards (Wolf *et al.* 2013). Exposure may be defined in general as "the degree, duration, and/or extent in which a system is in contact with, or subject to, a perturbation" while sensitivity is "the degree to which a system is modified or affected by perturbations" (Adger 2006; Gallopín 2006).

This approach to determining vulnerability starts by formulating future climate scenarios, typically through models that predict changes in the global climate and subsequent impacts. More specifically, a series of hierarchical models, beginning with predictions of world development and greenhouse gas emissions trends which lead to development of global and regional climate models, and finally impact models, are used to determine the exposure and sensitivity of primarily physical systems (e.g. water resources, infrastructure) to future climactic hazards across spatial and temporal scales (Dessai *et al.* 2004). Climate models, which predict a system's future exposure to hazards such as a decrease in rainfall or sea level rise, are often based on highly sophisticated simulations. Impact models, which determine a system's future sensitivity, can range from complex, large-scale models to simpler dose-response functions (observing the change in effect on a system as levels of exposure to a hazard change) based on past and present experiences and understanding of system behaviour at local scales.

A final optional step to an outcome vulnerability analysis is to consider adaptations to reduce the risk or impact of possible hazards. These adaptations are designed to offset the

expected future exposure or sensitivity of the system to specific hazards and, in practice, often centre on the identification and implementation of technologies (O'Brien *et al.* 2007; Tschakert & Dietrich 2010). The practice of designing technologies or infrastructure to resist climactic hazards is sometimes called 'climate-proofing'. A suite of possible adaptation options may be considered and are commonly ranked using cost-benefit, cost effectiveness, or multiple criteria analyses (Smit & Wandel 2006), although there is increasing awareness that social and environmental impacts also must be taken into account.

Contextual vulnerability

In the late 1990s, often in response to risk/hazard analyses, more attention started to be given toward the non-climactic drivers that caused certain social groups to be more susceptible to harm from climate change than others (Eakin & Luers 2006; Füssel & Klein 2006). This led to the conceptualisation of 'contextual vulnerability' (O'Brien *et al.* 2007). This conceptualisation views vulnerability as an inability to cope with external pressures and changes in general (O'Brien *et al.* 2007). It is a function of *present* socio-economic, institutional, and ecological factors and processes (O'Brien *et al.* 2007; Wolf *et al.* 2013).

While a contextual vulnerability approach considers environmental systems, the focus is largely on social systems consistent with its origins in social and critical theory (Turner 2010). It draws attention to concepts such as agency and empowerment, and emphasises the potential for climate change to exacerbate the social conditions that create poverty and inequality (Miller *et al.* 2010; Leichenko & Silva 2014). Studies of contextual vulnerability often seek to understand which social groups are least able to adapt to external stressors and why (Ford *et al.* 2010). They tend to address issues of political economy in specific places (Eakin & Luers 2006) and recommend a broad range of solutions that are based on the context of the studied area (Ford *et al.* 2010). The main way a contextual vulnerability approach differs from a conventional development approach is its increased attention on preparing communities for uncertainty and living in increasingly risky settings (Lemos *et al.* 2013).

An important concept for contextual vulnerability is building adaptive capacity. Adaptive capacity may be generally understood as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC 2014b). Authors have suggested numerous determinants of adaptive capacity including access to assets or capitals, equitable institutions, adaptive management (a management strategy based on continual learning through experimentation and innovation) practices, transparency, accountability, and empowerment (Jones *et al.* 2010; Engle 2011; Ensor *et al.* 2015). It should be noted that adaptive capacity also features in some outcome vulnerability analyses (O'Brien *et al.* 2007). The difference is that an outcome approach tends to focus on the capacity to adapt to identified risks, whereas a contextual approach focuses on the capacity to adapt to uncertainty in general.

Resilience

The resilience perspective emerged from the field of ecology in the 1960s and 1970s and has evolved to take on different meanings (Folke 2006). One conceptualisation has been termed 'engineering resilience' and may be measured in terms of resistance to disturbance and speed of return to equilibrium after being displaced (Holling 1996). It is important to note that resistance, measured by the amount of force or pressure needed to displace or disturb

an entity by a given amount, is considered to be an attribute of resilience rather than synonymous with it (Carpenter *et al.* 2001).

Over time, this linear understanding of resilience fell out of favour with researchers studying social-ecological systems (SESs), systems comprising interacting social and ecological components, as being too simplistic when applied to complex and adaptive environmental and human systems (Folke *et al.* 2010). Climate change resilience scholars have predominantly focused on the resilience of SESs (Bahadur *et al.* 2013) which are typically analysed drawing on the concept of 'ecological resilience' (Folke 2006). It is this form of resilience that we refer to throughout the rest of this paper unless otherwise noted. Ecological resilience is characterised by the amount of change or disturbance a system can experience without shifting to an alternate state that has different structural and functional properties (Resilience Alliance 2010).

Five important concepts of resilience thinking in regard to how complex SESs function are self-organisation, thresholds, linked domains, adaptive cycles, and linked scales (Walker & Salt 2012). Self-organisation refers to the ability of interacting components of a system to organise themselves without the need for external forces, and is viewed as a primary determinant of resilience (Carpenter *et al.* 2001).

Thresholds represent breakpoints between alternative stable states in which a system can exist (Resilience Alliance 2010). For example, a healthy freshwater source may continue receiving an excess of nutrients until a threshold is reached, then abrupt and extensive algal blooms occur to the detriment of other aquatic life (Millennium Ecosystem Assessment 2005).

The concept of linked domains refers to the interplay between the social and ecological domains. In particular, the focus is on how the structure and function of ecosystems influence services delivered to society and vice versa (Turner 2010).

The adaptive cycle represents an analytical framework for the dynamics of an SES which postulates that complex systems pass cyclically through four phases (Gunderson & Holling 2001): rapid growth and exploitation characterised by accumulation of capital, conservation characterised by stability, collapse characterised by uncertainty and breaking of linkages between system sub-components, and renewal characterised by reforming of the same or new linkages between sub-components. The key feature of this concept is that opportunities for novelty usually happen during the collapse and renewal phases (Carpenter *et al.* 2001).

The idea of linked scales points to the fact that complex systems are often influenced by other systems that they are nested within or encompass at larger or smaller spatial scales, and have a dynamic, long-term temporal dimension (Adger *et al.* 2005). Importantly, this idea highlights the concern of maladaptation – the potential for adaptation actions to negatively affect the target group in the future or harm people or places linked at other spatial scales (IPCC, 2014a).

Reviews of the resilience literature have identified a number of system properties that influence levels of SES resilience. These include diversity, redundancy, connectivity, openness, feedbacks, and slow-changing variables (Biggs *et al.* 2012; Walker & Salt, 2012). These are summarised in Table 1 below.

172 **Table 1. Properties of resilience**

Property	Definition
Diversity	The variety of ways in which system elements can respond to a disturbance
Redundancy	The presence of system elements that can compensate for one another
Connectivity	The way and degree to which different system components interact with one another
Openness	The ease with which ideas, species, and people can flow in and out of a system
Feedbacks	When a change in one system component is reinforced or dampened by a subsequent change in another component
Slow-changing variables	System variables that change slowly over time and subtly determine the underlying structure of a system

173 Adapted from Biggs *et al.* (2012) and Walker & Salt (2012)

174 These properties are present in both the social and ecological sides of an SES (Walker &
175 Salt 2012). Too much or too little of diversity, redundancy, connectivity, and openness can
176 reduce a system's resilience, and feedbacks and slow-changing variables can have positive
177 or negative effects (Biggs *et al.* 2012; Walker & Salt 2012). Key to a resilience approach is
178 management of these properties to adjust them to the most beneficial levels.

179 Reviews have also identified governance processes that build system resilience. These
180 include continual learning and experimentation, appreciation of complex system dynamics,
181 inclusive and polycentric decision-making, and strong leadership, trust, and social networks
182 (Biggs *et al.* 2012; Walker & Salt 2012; Bahadur *et al.* 2013). An appreciation of complex
183 system dynamics refers to an understanding of the resilience concepts and properties as
184 described above. While the linkages between adaptive capacity and resilience generally are
185 not well articulated (Cutter *et al.* 2008), it is notable that there is significant overlap between
186 vulnerability and resilience thinking when it comes to building adaptive capacity or resilience
187 of governance and management mechanisms (Engle 2011).

188 A summary of the characteristics of these three perspectives is shown in Table 2 below.

189 **Table 2. Key elements of vulnerability and resilience perspectives**

Characteristics	**Outcome vulnerability**	**Contextual vulnerability**	**Resilience**
Key concepts	Exposure, sensitivity, hazards	Adaptive capacity, equality	Thresholds, self-organisation, linked domains and scales
Primary systems of interest	Physical	Social	Ecological, social-ecological
Timeframe of focus	Near future (as far as models will allow)	Present	Long-term future
Common analytical objectives	Identify hazards and consider likelihood	Understand who is least and most likely	Understand interactions within

	and severity of their impacts	to cope with changes in environment and why	and between systems and what causes systems to shift to a new equilibrium
Commonly recommended adaptation options	Implementing technologies, climate-proofing infrastructure, improving management of technology	Reducing inequalities, empowering people to cope with external stresses in general, poverty alleviation	Optimising or managing resilience properties, developing resilient governance structures and processes

WASH and climate change literature

Having provided an overview of the prominent vulnerability and resilience approaches in the climate change literature, we now turn to the scholarly WASH literature to examine the extent to which these three approaches are employed.

Methodology

This sub-section describes our methodology to locate and analyse scholarly WASH literature with a climate change focus. We chose this theme because it is quickly gaining interest and scholarly studies typically contain more theoretical discussion than grey literature. We focused on peer-reviewed literature, although we have also included non-peer reviewed reports that were rigorous, fully cited, and well argued. WASH and climate change are not fields of scholarship with clearly delineated boundaries, so it was necessary to delimit our literature review in several ways.

First, we reviewed literature that primarily focuses on access to WASH services. Thus, we did not review the expansive body of literature on climate change impacts on water resources management, or the growing epidemiological body of literature on WASH-related diseases driven by climate change. Not all literature falls clearly between these categories, so at times we had to make a judgement on whether a particular paper had enough of a service delivery focus to be included in our review. Second, we sought literature that included a focus on the delivery of WASH services for domestic uses. Thus, we did not include literature focused on multiple productive uses of water such as community-scale agriculture. Third, we sought literature that has an explicit focus on developing countries. Finally, the literature must have included the impacts of or adaptation to climate change for WASH services as one of its primary areas of analysis to be a part of our review. We did not review literature pertaining to WASH and disaster risk reduction if there was no focus on climate change, or literature pertaining to WASH and climate change mitigation.

Relevant scholarly literature was obtained through searches on ProQuest and Web of Science databases, and on Google Scholar. We used numerous search strings containing the terms “climate change”, “water service”, “water access”, “water supply”, “water supplies”, “drinking water”, “household water”, “domestic water”, “sanitation”, “hygiene”, and “WASH”. To these terms, we also added a custom-made search string containing over 100 country names and related terms to identify studies that focus on developing countries. Papers were initially screened by reviewing titles and abstracts for relevance. The contents of 59 papers

were screened more in-depth using the delimitations described above, and 33 were selected to be included in this study.

Each of the 33 papers was reviewed to identify to which theoretical vulnerability or resilience approach they are most closely aligned. This was performed by drawing on a diagnostic tool developed by O'Brien *et al.* (2007) to identify vulnerability interpretations through examination of research questions, methods, results, and recommendations, a list of analytical focal points provided by Miller *et al.* (2010) that distinguish vulnerability and resilience studies, and our own expert knowledge.

Limitations

A first limitation of this study was the subjective nature of judging what qualifies as "scholarly WASH literature" and what implicit theories were used by the authors. We have described our strategy for identifying relevant WASH literature, but it is possible that other researchers would include more, or exclude some we have used, based on their own interpretations. Other researchers may also interpret the implicit theories behind some of the literature differently than us. We have mitigated this effect through the involvement of three authors in critiquing the literature and by presenting summaries of the key points of the reviewed papers.

Vulnerability and resilience also feature in the literature of the closely related fields of disaster risk reduction and general development for WASH, as well as in grey literature. These other bodies of literature are also influential on how the WASH sector understands vulnerability and resilience, but are expansive and deserving of their own separate reviews.

Summary of literature

In this sub-section we present brief summaries of the reviewed literature and their recommendations. Each is categorised as having a predominant orientation toward (i.e. generally aligning itself with) one of the three discussed vulnerability or resilience approaches, or as drawing on two or more of the approaches in a fairly balanced way. We found that 17 of the reviewed papers had a predominant outcome vulnerability orientation, five had a predominant contextual vulnerability orientation, two had a predominant resilience orientation, and nine evenly balanced two or more approaches. Notably, outcome vulnerability is represented in all of the nine balanced papers. 22 of the reviewed papers focused on water, one focused on sanitation, and ten considered both.

Literature with a predominant outcome vulnerability orientation

One of the most common focal points that the reviewed literature covers is the direct impact of certain projected climate change hazards on WASH technologies. How specific climactic hazards can cause physical damage to or directly disrupt functionality of an array of technologies, and which technologies are most likely to resist hazards under a range of climate change scenarios, has been described in detail (Bonsor *et al.* 2010; Howard *et al.* 2010; Sherpa *et al.* 2014). Some studies focus on technologies that are commonly used in a particular region and consider only climactic hazards that are geographically relevant to them. For instance, specific impacts of climate change on wells and latrines in Mauritania (Cissé *et al.* 2016), spring-fed water systems in Bolivia (Fry *et al.* 2012), groundwater supplies in southeast Asia (Hoque *et al.* 2016), small scale sand dams in Ethiopia (Lasage *et al.* 2015), various small scale water supplies in Bangladesh (Rajib *et al.* 2012), mountain spring-fed water systems in India (Tambe *et al.* 2012), and rural groundwater supplies in

Africa (MacDonald *et al.* 2009; Bonsor *et al.* 2010) have been the subject of in-depth studies. These studies all make recommendations for promoting technologies, or modifications to existing technologies, that will resist disruption when exposed to particular climate change induced hazards.

Investigation of climate change risks to the management of technologies is also an area of attention. Studies have investigated the capacity of utilities and communities to make repairs and modifications to water infrastructure affected by climactic hazards (Howard *et al.* 2010), as well as the financial costs of abstracting and delivering water for small towns under changing rainfall conditions (Mukheibir 2010a). Attention has also been given to development of strategies for management of water service infrastructure and resources threatened by climate change in the Caribbean (Cashman 2014).

To help offset impacts of climate change, guides or tools have been developed to assist WASH service implementers in managing technologies. Elliot *et al.* (2011) presented a catalogue of technologies and managerial practices with guidance on how they can be applied to reduce the impact of climate change hazards. Heath *et al.* (2012) field tested a tool for downscaling regional climate models and generating recommendations for climate-proofing water and sanitation infrastructure. Oates *et al.* (2014) presented a three-step process of assessing the risks of climate change hazards against other large-scale stressors on WASH, evaluating the extent to which adaptation options can reduce these risks, and prioritising the options using cost-benefit analysis. Meanwhile, Doczi (2013) reviewed 137 practitioner tools designed for, or that could be reappropriated for, managing climactic risks to WASH. Many of the recommendations resulting from these managerial focused papers aim to optimise technical and financial efficiency and effectiveness in managing identified risks.

How WASH technological adaptations can be maladaptive was explored little. One such example is the potential of water storage and rainwater harvesting, promoted as climate change adaptations, to spread disease (Boelee *et al.* 2013).

Literature with a predominant contextual vulnerability orientation

Five of the reviewed papers had a predominant contextual vulnerability orientation. One study investigated how people draw on a range of assets that are mediated through institutions, such as religion and cultural values, to secure freshwater in Kiribati (Kuruppu 2009). Differential access to assets, power relations exploited through institutions, and perceptions of adaptation are shown to influence the capacity of these people to adapt their water sources (Kuruppu 2009; Kuruppu & Liverman 2011). How differing perceptions between genders on water availability (Mudombi & Muchie 2013) and unequal access to land rights and tenure (Khatri & Shrestha 2014) may influence coping or adaptation action related to WASH services has also been examined. At a larger scale, it has been argued that while climate-proofing of water developments is needed, vulnerability is largely based on social and economic factors and a conceptual shift in adaptation thinking is needed to focus more on securing long-term livelihoods in water-climate change nexus policy in Ethiopia (Oates *et al.* 2011).

Many of the recommendations following these studies focus on enabling people to adapt to external stressors in general. The nature of these recommendations include addressing power structures within influential organisations (Kuruppu 2009), improving or managing

feelings of self-efficacy (Kuruppu & Liverman 2011), empowering individuals to overcome local barriers to adaptation action (Kuruppu 2009; Mudombi & Muchie 2013), alleviating poverty (Khatri & Shrestha 2014), and maintaining attention on existing development issues at the core of climate change adaptation work (Oates *et al.* 2011).

Literature with a predominant resilience orientation

Two of the reviewed studies could be seen to have a predominant resilience orientation. Adaptive co-management, claimed to be a successor to resilience thinking, is proposed as a potentially effective approach to adapting rural water services to climate change (FitzGibbon & Mensah 2012). This approach focuses on analysing the complex and cross-scale interconnections between multiple factors and processes affecting water management, promoting continuous learning, and building social capital (FitzGibbon & Mensah 2012). Integrated water resources management (IWRM) is another approach based on a holistic understanding of how water-related systems interact with one another that is proposed for managing WASH services under climate change (Hadwen *et al.* 2015). Both studies emphasise the importance of jointly considering all linked systems relevant to water service.

Much of the literature without a predominant resilience orientation, intentionally or not, touches on some resilience governance principles. Several papers note that considering linked domains in the context of WASH and climate change is important and some suggest IWRM or other frameworks may be used to address this (Smits *et al.* 2009; Bonsor *et al.* 2010; Mukheibir 2010b; Batchelor *et al.* 2011; Calow *et al.* 2011; Elliot *et al.* 2011; Srinivasan *et al.* 2013). Monitoring and information gathering, especially on water resources, to support continuous learning is recommended by many authors (Smits *et al.* 2009; Batchelor *et al.* 2011; Calow *et al.* 2011; Elliot *et al.* 2011). Mukheibir (2010b) emphasises that water managers need to plan adaptation for fast-changing variables like extreme events differently than slow-changing ones like gradual precipitation change.

Resilience properties of WASH are also demonstrated. Diversification of water supplies in order to “spread out” risk such that the likelihood of one perturbation disrupting all services is lessened (Kuruppu 2009; Calow *et al.* 2011; Elliot *et al.* 2011) and increased redundancy through increased water storage capacity or development of multiple water supplies (MacDonald *et al.* 2009; Howard *et al.* 2010; Batchelor *et al.* 2011; Boelee *et al.* 2013) are encouraged. Bonsor *et al.* (2010) state that boreholes or deep wells that reach 20 metres below the ground surface in rural Africa are likely to avoid depletion under future climate scenarios. This could be considered an important threshold. However, along these same lines, MacDonald *et al.* (2009) note a possible feedback loop whereby users of shallow groundwater sources may abandon their failed systems and move to more robust deep groundwater supplies which in turn could fail due to the increased stress from a rising number of users. Finally, Howard *et al.* (2010) recommend decentralising water infrastructure to reduce the spread of risk through highly connected water supplies, but centralising water management to maximise the use of people with needed skillsets. This can be seen as management of the property of connectivity.

Literature balancing multiple approaches

Two of the reviewed studies provide discussions that blend all three approaches in a fairly even-handed manner. Mukheibir (2010b) argues that prominent discourses for addressing water scarcity and equitable water access under climate change in developing countries follow along discrete policy agendas with little interaction. Others highlight the strengths and

355 weaknesses of viewing adaptation of water service provisioning to climate change through
356 different disciplinary perspectives (Srinivasan *et al.* 2013). Both of these studies recommend
357 strategies to harmonise the principal objectives of differing paradigms.

358 Other papers have balanced discussion of each vulnerability perspective and draw on
359 resilience. Batchelor *et al.* (2009, 2011) and Smits *et al.* (2009) state that specific risks from
360 climate change to WASH services must be managed, but WASH actors also need to be
361 enabled to adapt to uncertainty in general. The authors' recommendations of strengthening
362 capacity, improving governance, and adopting adaptive management principles could follow
363 along any approach depending on how they are applied. Calow *et al.* (2011) provide a broad
364 overview of adaptation strategies and policy responses that address the threat of climate
365 change to WASH and explicitly distinguish perspectives. The authors offer a range of
366 recommendations including emphasising the importance of resource access and
367 entitlements, screening WASH investments for climate risks, and promoting technologies
368 that are appropriate for a range of climactic conditions.

369 The three remaining papers concentrate on case studies that draw equally on outcome and
370 contextual vulnerability approaches. Alamgir *et al.* (2016) state that future climate change
371 hazards are likely to exacerbate existing surface water issues, including inequitable
372 distribution, in coastal Pakistan. Two other studies seek to characterise enablers and
373 barriers facing rural and urban water service providers in managing identified risks of future
374 climate change, but also cover numerous existing socioeconomic and political factors that
375 affect their ability to adapt to external stress in general (Ziervogel *et al.* 2010; Ojomo &
376 Bartram 2016). Recommendations from these latter studies include improving partnerships
377 across disciplines, strengthening technical and human resource capacity, building leadership
378 and will to act on climate change, promoting awareness of climate change impacts, and
379 linking adaptation to development priorities (Ziervogel *et al.* 2010; Ojomo & Bartram 2016).

380 A summary of our categorisations is shown in Table 3 below.

381 **Table 3. Summary of the predominant theoretical orientations of the reviewed**
382 **literature**

Predominant theoretical orientation	Reference
Outcome vulnerability	Bonsor *et al.* 2010; Boelee *et al.* 2013; Cashman 2014; Cissé *et al.* 2016; Doczi 2013; Elliot *et al.* 2011; Fry *et al.* 2012; Heath *et al.* 2012; Hoque *et al.* 2016; Howard *et al.* 2010; Lasage *et al.* 2015; MacDonald 2009; Mukheibir 2010a; Oates *et al.* 2014; Rajib *et al.* 2012; Sherpa *et al.* 2014; Tambe *et al.* 2012
Contextual vulnerability	Khatri & Shrestha 2014; Kuruppu 2009; Kuruppu & Liverman 2011; Mudombi & Muchie 2013; Oates *et al.* 2011
Resilience	FitzGibbon & Mensah 2012; Hadwen *et al.* 2015
Equal balance of multiple perspectives	Alamgir *et al.* 2016; Batchelor *et al.* 2009; Batchelor *et al.* 2011; Calow *et al.* 2011; Mukheibir 2010b; Ojomo & Bartram 2016; Smits *et al.* 2009;

Discussion

In this section we first present our overall impression of the reviewed literature. We then follow with a discussion of the limitations and opportunities of working along different approaches within the WASH sector, and end with a discussion on how the process of working between different approaches may be navigated.

Limited conceptual awareness

The terms vulnerability and resilience were used frequently throughout the literature, but very few authors attempted to define or even characterise them. However, our study has found that the outcome vulnerability approach is implicitly drawn on most frequently. One explanation for this is that the WASH sector is reflecting the tendency of the wider climate change scholarship and policy to favour a scientific framing of climate change as a biophysical problem (O'Brien *et al.* 2007). Another possible explanation is that when WASH authors without a strong grounding in climate change adaptation theory are met with the conflicting definitions presented by the climate change literature, they default to definitions provided by the IPCC which is widely seen as the authoritative body on climate change. The IPCC definition of vulnerability aligned mostly with an outcome approach until the definition was changed in the 2014 Fifth Assessment Report to be more encompassing of different interpretations. Meanwhile, the resilience concept historically has had weaker links with climate change adaptation research than vulnerability (Janssen *et al.* 2006).

Regardless of the reason, the apparent lack of conceptual awareness in WASH-climate change nexus literature is cause for concern. Authors often seemingly take definitions of vulnerability and resilience as given. However, as we have demonstrated in the literature review, these concepts can manifest in different approaches that tend to produce different outcomes. Failure to define key concepts is likely to lead to confusion and adaptation approaches that are incongruous with one another in the WASH sector. Further, WASH-climate change policy that overlooks the range of available perspectives could allow a narrow domain of solutions to dominate. This latter potential outcome requires attention due to inherent limitations or weaknesses of each approach for the WASH sector.

Limitations and opportunities within the WASH sector

Many of the recommendations coming from the WASH literature that predominantly follow an outcome vulnerability approach are technological and reliant on climate models that have considerable uncertainty. Robust technology clearly is important for WASH service provision, but poor communities are least likely to be able to implement and maintain climate-proofed infrastructure, like raised latrines to protect against floods, due to their higher costs and knowledge required to build and operate safely. Thus, promotion of WASH technologies that are resistant to climate change hazards must be accompanied by strategies to make these technologies available to all social groups in order to avoid reinforcement of inequalities in WASH access. Climate change is also just one of many difficult circumstances that communities face and WASH adaptation solutions will be more successful if they also address the everyday priorities of communities. In fact, too much focus on promoting "resilient" (in the engineering sense) WASH technologies that are designed for specific hazards can undermine general resilience in other ways (Folke *et al.* 2010), such as by

reducing the diversity of options for accessing WASH. Further, over-reliance on climate change projections that have large uncertainty at the local scales where WASH services are usually managed (Batchelor *et al.* 2011) risks wasteful investment if climate change effects manifest differently than expected. This latter concern may be in addressed in part by drawing on the literature that has identified which WASH technologies are resistant to the widest range of climactic hazards.

Contextual vulnerability strategies can be too localized, too present-focused, or not novel enough to address the cross-scalar effects of climate change. This place-based approach to assessing and developing solutions to address WASH vulnerability may be piecemeal and difficult to scale up. Generic indicators for assessing WASH adaptive capacity could be developed based on socioeconomic data and access to WASH technologies or water resources, but vulnerability indicators for the purpose of comparison at large scales are roundly criticised for over-simplifying the complex and context-specific nature of vulnerability (Barnett *et al.* 2008; Hinkel 2011). Further, a focus on achieving near-term gains that benefit present vulnerable groups risks neglecting long-term environmental sustainability (Eakin *et al.* 2009). Indeed, the WASH sector has paid relatively little attention to upstream (water source reliability) and downstream (sanitation pollution) effects compared to improving access in the near-term (Carrard & Willetts in press) and these effects will be exacerbated by climate change. Finally, many of the solutions recommended by the WASH literature that takes a contextual vulnerability orientation are akin to conventional development approaches which may lack necessary innovation and concerted action to tackle unprecedented climate change impacts. Climate change presents many different risks, (e.g. changes in precipitation, strengthening of extreme events, sea level rise, etc.), and it is worthwhile to consider how management of these risks can be integrated with conventional development approaches.

The principle criticism surrounding resilience is difficulty in translating theories and models developed in the field of ecology into social systems. In particular, resilience approaches tend to omit or underplay social-political dimensions such as power relations and cultural values (Cote & Nightingale 2012) and may draw attention away from the traditional pro-poor objectives of aid and development (Béné *et al.* 2012). These dimensions are important to account for considering that inequality and systemic discrimination are major barriers to water and sanitation access (Van de Lande *et al.* 2015), and that climate change has potential to exacerbate inequality (OHCHR n.d.). Understanding how resilience concepts and properties can be measured or assessed in social systems remains a challenge. Another issue is that resilience thinking focuses on the SES as the primary unit of analysis and it is not entirely clear how SES analyses should be extended to services, like WASH, that have a heavy technological component (McGinnis & Ostrom 2014). Lastly, taking a resilience approach requires additional investments for the future, usually at the expense of present cost-efficiency, (Eakin *et al.* 2009; Walker & Salt 2012) which may be difficult to encourage in resource-poor settings.

Yet, with these considerations in mind, each approach has significant value to contribute to preparing WASH services for climate change and is worthy of further investigation, especially the contextual vulnerability and resilience approaches which have received relatively limited attention in the literature. More research is needed on how contextual conditions influence the ability of WASH providers and users to pursue adaptation strategies. The Sustainable Livelihoods Approach (Scoones 1998) and the human rights to water and

sanitation framework are possible ways of integrating this approach to climate change into the WASH sphere. However, WASH experts will need to develop methods to make these approaches appropriate for the uncertain, increasingly risky, and unprecedented effects of climate change. It is not enough to simply embellish existing development approaches to WASH as climate change adaptation. Rather, we must also consider how popular WASH objectives, such as striving for piped water in every household or proliferation of septic tanks, will fare in settings where extreme events and rainfall variability may become more heightened than ever experienced before.

There is significant potential for operationalising and testing the concepts and properties of resilience in the context of WASH. Our review of the literature has highlighted some examples of how this may be done, but further conceptualisation, operationalisation, and observation of resilience principles and properties in a WASH context is needed. Centralising the management of water infrastructure may help spread the utility of hard to find skillsets, but a tightly managed top-down management style may also limit self-organisation. This trade-off requires more deliberation. Thresholds may be identified by asking questions like “how much sea level rise can a community experience before their groundwater supply becomes salinized?” or “at what point does rising water scarcity culminate in conflicts between users?” Frameworks for understanding the interactions between the social and ecological domains need to be made relevant for WASH services and tested. The idea of implementing novel ideas and changes during phases of collapse and renewal is gaining legitimacy, particularly in the field of post-disaster recovery, under the mantra “building back better” (Mannakkara & Wilkinson 2014) and its applications for climate change and WASH should be studied further. Finally, more empirical research is also needed to understand if and how resilient governance practices actually improve the ability of WASH providers to absorb shocks and stresses.

Working between different approaches

When developing WASH climate change adaptation policy, it will usually be advantageous to simultaneously draw on each approach in an integrated way to help minimise their inherent limitations. This is because the weaknesses of each often appear to be strengths of one of the others. But there is still a question of how this should be done. Should one attempt to balance all three approaches equally or, in the context of WASH services, does it make sense to depart from one approach and bring in the others later? We argue that the answer to this question is normative (i.e. what are the WASH components of interest and to what precisely are they adapting) and driven by values.

In some instances where climate change is being addressed for a specific reason, it may make more logical sense to use one orientation as a foundation and draw on the others to complement it. An outcome vulnerability orientation may be most useful for designing a rapid WASH disaster response plan to expeditiously restore WASH access after a specific extreme event. If one is interested in studying how climate change will affect the achievement of human rights to water and sanitation, the social focus of a contextual vulnerability orientation may be the most useful starting point. A resilience orientation may work best for preparing WASH services for long-term climate change in an area where water resources are especially fragile. In all of the above examples, we strongly recommend that WASH planners also consider how the other approaches could contribute and what are the potential consequences of emphasising one approach over the others.

However, in many cases there will be no obvious rationale for emphasising one approach over the others and this is when approaches can become contested due to differing values. Values in the context of climate change relate to forming ideas about what is considered effective and legitimate adaptation, what is worth preserving and achieving, and what should be the goals of adaptation (O'Brien & Wolf 2010). Experience shows that the success of climate change adaptation efforts is often limited when the values of implementers are not aligned with those who are meant to benefit (Adger *et al.* 2009).

This has implications for how climate change adaptation should be mainstreamed into WASH service policy. It could be argued that adaptation actions should prioritise a reduction in inequalities and empowerment of people to improve their access to WASH services so that they are better able to cope with the stresses of climate change. It could also be argued that a focus on climate-proofing or building resilience into WASH services gives enormous long-term benefits in terms of ensuring water security and reliable infrastructure. Ideally climate-resilient WASH services are developed without compromising near-term gains in access, but decision-makers must choose how to allocate scarce resources. Making a decision on this requires debating the ethics of delaying basic WASH service provision to build in additional measures to prepare for climate change, beliefs about the extent to which society should invest in enabling future generations to meet their needs, and the value that should be placed on the natural environment amongst numerous other axiological considerations. WASH policy-makers interested in mainstreaming climate change adaptation into policy must consider who stands to benefit most from taking different orientations and whose values will be privileged.

Politics are likely to factor into deciding which orientation to take. Social groups that rely on expensive water and sanitation infrastructure are more likely to advocate for an approach that manages climactic risks to technologies. In some areas, politicians who want to improve embarrassingly low coverage figures may be less inclined to take an approach that invests in the distant future. Whether intentional or not, groups that usually are in powerful positions, like the wealthy and international donors, will have unbalanced influence on how the WASH sector should incorporate climate change vulnerability and resilience into its agenda.

The newly formed SDGs offer an opportunity to consider how different approaches can be balanced. SDG 6 compels the WASH sector to achieve universal and equitable access to water and sanitation while also addressing water scarcity, preventing water pollution, and protecting ecosystems. Building bridges between equitable WASH access and water resource management offers a path toward achieving SDG 6 while also laying important groundwork for preparing for climate change impacts. However, the limitations of the SDGs for preparing WASH for climate change must also be acknowledged. The SDGs are conceptualised at national and international levels while the natures of vulnerability and resilience are often considered to be highly context-specific. This could lead to incongruence, for example, on the topic of hardware provision; the WHO/UNICEF Joint Monitoring Programme focuses on primary improved water and sanitation facilities, but does not consider the potential need for access to a diverse set of facilities or infrastructure that is resistant to local climactic hazards.

We are in agreement with others that limitations and contested values in the context of climate change should be addressed through consultation with stakeholders (Adger *et al.* 2009; Eakin *et al.* 2009) and improved knowledge on how to combine different approaches.

Increased appreciation of the differing conceptualisations of vulnerability and resilience and their significance for WASH services will assist stakeholders in developing meaningful discussion. In this paper we have sought to spur this appreciation and we encourage WASH professionals to continue to develop and discuss the concepts presented here and make them relevant to WASH users and associated ecosystems threatened by climate change.

Conclusions

In this paper we has sought to sensitise a WASH audience to competing theoretical perspectives on how society experiences and adapts to climate change, analyse the contributions of the WASH literature to this space, and to start a discussion on how the WASH sector should plan for and react to inevitable climate change. In particular, we have introduced theories of outcome vulnerability, contextual vulnerability, and resilience, and have found that the WASH literature primarily follows an outcome vulnerability orientation. We have argued that a narrow focus on any one perspective is limiting and have urged WASH experts to expand their appreciation of different assumptions and their consequences as they continue to work toward ensuring WASH services under a changing climate.

As climate change and climate change adaptation continue to increasingly feature in WASH policy, development work, and research, the messages from this study become more and more pertinent. The theoretical premise on which WASH experts implicitly or explicitly choose to address climate change largely influences their course of action and recommendations. Given that there are substantial inherent limitations to using different theories, it is paramount that consideration be given to who or what will stand to benefit most and who or what will lose out. This consideration cannot be given due and fair diligence unless different perspectives are acknowledged and deliberated by those implicated.

WASH as a field of aid and development has a rich history of drawing on a variety of disciplines and epistemologies to develop tools and methods that have engendered positive change. Although climate change is a threat unlike any the modern world has seen before, the same diverse range of thinking and action, developed through inclusive and fair debate and legitimate in the eyes of those under threat, provides the best approach for advancing adequate WASH services under changing climactic conditions.

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