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Expert assessment of the resilience of drinking water and sanitation systems to climate-related hazards

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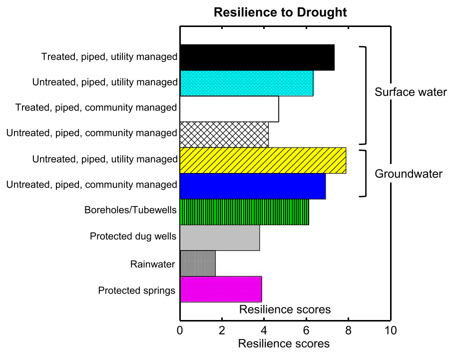
HIGHLIGHTS

- Assessed the resilience of water and sanitation technologies to climate extremes.
- Resilience scores ranged from 1.7 to 9.9 out of a maximum resilience of 10.
- Technologies demonstrated a large range in resilience for drought.
- Technologies demonstrated a small range in resilience for superstorm flooding.
- Results can be used for future adaptation planning and vulnerability assessments.

GRAPHICAL ABSTRACT



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ABSTRACT

We conducted an expert assessment to obtain expert opinions on the relative global resilience of ten drinking water and five sanitation technologies to the following six climate-related hazards: drought, decreased inter-annual precipitation, flood, superstorm flood, wind damage, and saline intrusion. Resilience scores ranged from 1.7 to 9.9 out of a maximum resilience of 10, with high scores corresponding to high resilience. We find that for some climate-related hazards, such as drought, technologies demonstrated a large range in resilience, indicating that the choice of water and sanitation technologies is important for areas prone to drought. On the other hand, the range of resilience scores for superstorm flooding was much smaller, particularly for sanitation technologies, suggesting that the choice of technology is less of a determinant of functionality for superstorm flooding as compared to other climate-related hazards. For drinking water technologies, only treated piped utility-managed systems that use surface water had resilience scores >6.0 for all hazards, while protected dug wells were found to be one of the least resilient technologies, consistently scoring <5.0 for all hazards except wind damage. In general, sanitation technologies were found to have low to medium resilience, suggesting that sanitation systems need to be adapted to ensure functionality during and after climate-related hazards. The results of the study can be used to help communities decide which technologies are best suited for the climate-related challenges they face and help in future adaptation planning.

1. Introduction

Climate change is shifting global weather patterns in a way that is predicted to impact both natural and anthropogenic systems such as

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freshwater resources and sanitation systems, respectively. Projections from the Intergovernmental Panel on Climate Change (IPCC) for the late 21st century (2081–2100) show a probability of 90–100% for an increase in the frequency, intensity, and/or amount of heavy precipitation events over most of the mid-latitude land masses and wet tropical regions, a 66–100% probability for increases in intensity and/or duration of drought on a regional to global scale, a 90–100% probability of increased incidence and/or magnitude of extreme high sea level, and a >50–100% probability for an increase in intense tropical cyclone activity in the Western North Pacific and North Atlantic (IPCC, 2013). In the near future (2016–2035), IPCC projections show a 66–100% probability for both an increase in frequency, intensity, and/or amount of heavy precipitation over many land areas and increased incidence and/or magnitude of extreme high sea level (IPCC, 2013). The occurrence of these extreme weather and climate events lead to an increase in fluvial erosion, salinization of coastal aquifers, reduction in water availability, and wind damage to structures in areas not accustomed to such events (IPCC, 2013, 2014a, 2008). In the case of water and sanitation systems, flood waters can cause physical damage to water and sanitation infrastructure; fluvial erosion from flooding can contaminate water supplies through the introduction of debris and pollutants (Islam et al., 2007; Kistemann et al., 2002); sea level rise and the resulting salinization of surface waters and coastal aquifers can lead to a decrease in water quality (Hay and Mimura, 2005); and decreased water availability from drought directly impacts the availability of water resources, the quality (Khan et al., 2015) of water (through increased pollutant concentration and salinization), and leads to wastewater with higher concentrations of pollutants that must be dealt with (IPCC, 2014a). In addition, the expected impacts of climate change may interact with each other, for example, coastal areas may experience both increased freshwater flooding and saline intrusion caused by sea-level rise, and tropical small island states may experience both tropical cyclone activity and sea level rise (IPCC, 2012). The effects of these climate-related events can leave water and sanitation systems non-functioning, exposing the population to various health risks (e.g., waterborne illnesses due to lack of safe water (IPCC, 2014a)). These risks impact both rural and urban populations in high income countries, and low and middle income countries.

To plan for and reduce the impacts of climate-related events to communities, studies have been conducted to assess the vulnerability and potential adaptability of water and sanitation systems (Sherpa et al., 2014; Heath et al., 2012; Charles et al., 2010). For example, Sherpa et al. (2014) examined the vulnerability of eight sanitation systems for floods and provided guidance on systems selections, while Heath et al. (2012) developed a vulnerability method for water and sanitation service providers in peri-urban and informal settlements in low-income settings. Vulnerability assessments can also be carried out to identify the regions or populations of highest vulnerability to loss of access to drinking water or sanitation (Luh et al., 2015; Elliott et al., 2014; Ojomo et al., Submitted; Banerjee, 2012). As part of these assessments, the types of drinking water and sanitation technologies used in a region or community as well as their resilience to different climate-related events must be known, where resilience is related to the water or sanitation technology's ability to absorb disturbances from climate-related events while maintaining its same basic structure and ability to function (Charles et al., 2010). Studies determining the resilience of drinking water and sanitation technologies to climate-related events have reported qualitative resilience ratings of 'high', 'medium', and 'low' for different water and sanitation technologies (Charles et al., 2010; Rajib et al., 2012; Howard et al., 2010; Calow et al., 2011). As an example, Rajib et al. (2012) evaluated the technological resilience of small drinking water systems (e.g., pond sand filters, dug wells, deep and shallow tubewells) in coastal areas of Bangladesh using the high, medium, low classification scheme of Howard et al. (2010). These qualitative assessments (Rajib et al., 2012) of resilience were based on long-term field surveys using both user and expert opinions under projected climate change and provide valuable insight on the potential technological resilience. However, when vulnerability assessments are conducted for the purpose of comparing, ranking, and/or identifying regions of highest vulnerability – for example, comparison of coastal counties in North Carolina, United States – numerical scores or indices for vulnerability are often needed. As such, there is a need to have numerical values of resilience that can be used in the calculations of vulnerability scores or indices. In the absence of numerical resilience scores, Banerjee (2012) and Luh et al. (2015) assigned values of 0.1, 0.4, 0.7, and 1 to correspond to the qualitative assessments of high, medium, low, and no resilience, respectively, from Howard et al. (2010); however, these scores assume that the difference between low and medium resilience is the same as the difference between medium and high resilience, which may not be true. In addition, it is unclear whether 'low' would have the same meaning across all technologies or whether 'low' could translate as 0.7 for one technology and 0.9 for a different technology. There is therefore a need to quantify how climate-related hazards can impact the resiliency of water and sanitation technologies. These scores of resilience can then be used to more accurately assess vulnerability.

Accordingly, this study aims to provide numerical scores of resilience for different types of improved water and sanitation systems to climate-related hazards. We conducted an expert assessment, which is a form of qualitative assessment, to obtain opinions on the resilience of ten drinking water and five sanitation technologies to the following six climate-related hazards: drought, decreased inter-annual precipitation, flood, superstorm flood, wind damage, and saline intrusion. While existing studies (Charles et al., 2010; Howard et al., 2010) group precipitation-related events as 'increase in precipitation' or 'decrease in precipitation', we differentiate between flood and superstorm flood (as well as drought and decreased inter-annual precipitation) because the impacts of the two events are different and thus the resiliency of a technology to these events may also be different. The results of the expert assessment were used to obtain a single resilience score for each pairing of climate-related hazard and water/sanitation technology. In addition to using these resilience scores in vulnerability assessments, determining the resiliency of different water/sanitation systems may help communities decide which technologies are best suited for the climate-related challenges they face and will help in future adaptation planning.

2. Methods

2.1. Expert assessment approach

Expert elicitation and expert structured judgment are two common systematic processes used to obtain and quantify expert judgment about uncertain quantities when conventional scientific research is not feasible (USEPA, 2011). While similar in purpose, the USEPA has defined expert elicitation as a method focused solely on characterizing the state of knowledge; and expert structured judgment as a method that focuses on characterizing both the state of knowledge as well as social values and preferences (USEPA, 2011). Both methods are often used in risk assessment (e.g., likelihood of volcanic eruption (Klugel, 2011), consequences of nuclear accidents (Cooke and Goossens, 2000a), increase in human mortality due to air pollution (Tuomisto et al., 2005; Roman et al., 2008)), where probabilistic distributions are typically obtained, although non-probabilistic elicitations and judgments have also been conducted (e.g., health impacts (Forsberg et al., 2012) and (re-)emergence of infectious diseases (Cox et al., 2012) associated with climate change). For the purposes of our study – determining the resilience of drinking water and sanitation technologies to climate-related hazards relative to other technologies (i.e., the study objective is not to determine probability of failure) – we used a modified form of Cooke's method (also known as the classical model) for expert structured judgment to obtain relative resilience scores. Cooke's method for expert structured judgment consists of 15 steps divided into the following three categories: preparation for elicitation, elicitation, and post-