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Changing water system vulnerability in Western Australia's Wheatbelt region

B. Boruff[a,*], E. Biggs[a,b], N. Pauli[a], N. Callow[a], J. Clifton[a]

[a] UWA School of Agriculture and Environment, University of Western Australia, Crawley, Perth, WA, Australia
[b] Geography and Environment, University of Southampton, Southampton, SO17 1BJ, UK

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A B S T R A C T

Within a changing world where freshwater resources are coming under increasing pressure, assessing water system vulnerability is critical for enabling adequate water resource management. Quantitative assessments of socio-economic and environmental factors which contribute to water system vulnerability can provide a strong evidence base on which to base decision-making. A range of drivers including population growth, agricultural intensification and industrial activity are placing greater demand on freshwater supplies in Western Australia. In combination with changing climatic conditions resulting in a warmer and drier environment in southwest Western Australia, these pressures have diminished the quantity of available freshwater supplies for agricultural districts. In this paper we provide a quantitative assessment of water supply and demand vulnerabilities for the Wheatbelt region of the state of Western Australia (WA). This region provides significant agricultural and mineral resource contributions to the state economy. The potable water supply for human consumption in this region is almost entirely drawn from a different geographic area, and conveyed by means of an extensive pipeline network to the Wheatbelt region. Competition for freshwater resources is high with increasing population pressures from expansion of the state's capital city, Perth, encroaching north- and eastwards into the Wheatbelt. To assess water vulnerability we conceptualise the water system components and select a series of socio-economic and environmental indicators which best represent the inherent vulnerabilities associated with water supply and demand in the Wheatbelt. Water supply, demand and overall system vulnerabilities were spatially assessed for the years 2001, 2006 and 2011. Results indicate that biophysical indicators of supply capacity have the greatest influence on overall vulnerability for each time period, however the spatial variability of specific vulnerability factors is much more nuanced. Our assessment of water vulnerability will enable water resources managers and policy-makers within the Wheatbelt and at the state level to better assess water supply and demand pressures. However, our robust methodology also allows for transferability to other locations experiencing water stress as a comprehensive approach for examining historic and future impacts of water resource availability on socio-ecological systems.

1. Introduction

Water availability is concerned not only with physical reserves of water, but also with the accessibility, use and sharing of water resources. Water availability plays a fundamental role in sustaining the environment, promoting wellbeing and providing opportunity for development, and is essential for attaining water, energy and food security (Biggs et al., 2015; Hoff, 2011). Exposure of the water system to shocks, stress, disturbance or increases in sensitivity can result in water resource vulnerability, and the ability of water system users to cope, recover or adapt following a disturbance to the system influences the magnitude of vulnerability (Adger, 2006; Turner et al., 2003). Although these aspects of social-ecological system functions are notoriously difficult to quantify and model, comprehensive analyses of vulnerability have been undertaken in many sectors, particularly for climate change (Preston, Yuen, & Westaway, 2011) and environmental hazards (Cutter, Boruff, & Shirley, 2003), but also with regard to agricultural systems (Sietz, Lüdeke, & Walther, 2011), livelihoods (Kok et al., 2016), water (Vörösmarty et al., 2010), and even phosphorus (Cordell & Neset, 2014). There is no universally accepted method for assessing the vulnerability of water resources, yet an integrated water vulnerability index has the potential to result in more effective social-ecological system function by addressing aspects of water scarcity, promoting sustainable development, providing information for decision-making

* Corresponding author. UWA School of Agriculture and Environment (M004), University of Western Australia, 35 Stirling Highway, Crawley, 6009, WA, Australia.
E-mail address: bryan.boruff@uwa.edu.au (B. Boruff).

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and enabling better disaster risk reduction strategies (Bitterman, Tate, Van Meter, & Basu, 2016; Sullivan, Cohen, Faurés, & Santini, 2008).

Consequently, this research develops a comprehensive framework using an integrated water vulnerability index to assess water system vulnerability in the Western Australian Wheatbelt. The framework was applied using a Geographic Information System (GIS) as an analytic tool, incorporating multiple socio-economic and environmental datasets to assess the spatial variability and temporal dynamics of water system vulnerability through components of supply and demand. The paper describes a conceptual framework and detailed methodology for assessing water vulnerability, and reports results for quinquennial change (2001–2011) in water system vulnerabilities across the study area. Our framework builds on existing published methods used to assess water vulnerability and incorporates locally relevant system information, providing a detailed and transferrable model that can be used in other regions as a planning tool for identifying key contributing factors to water system vulnerability.

2. Measuring water vulnerability

Assessment of water vulnerability has focussed on the vulnerability of water supplies to contamination (e.g. Doerfliger, Jeannin, & Zwahlen, 1999; Rupert, 2001), the vulnerability of physical water supply infrastructure (Chen, Niu, Bai, & Wang, 2014; Sahin & Stewart, 2013), and 'water stress' through the use of indicators comparing water withdrawals and surface water runoff (Jackson et al., 2001; Vörösmarty, Green, Salisbury, & Lammers, 2000). The need to include social, economic and institutional factors in water resource vulnerability assessment is gaining greater recognition as water security can be more closely tied to governance and management than to the physical abundance of water (e.g. Biggs, Duncan, Atkinson, & Dash, 2013; Cook, Fisher, Andersson, Rubiano, & Giordano, 2009; Kemp-Benedict et al., 2011; Pandey, Babel, Shrestha, & Kazama, 2010; Srinivasan, Lambin, Gorelick, Thompson, & Rozelle, 2012). However, socio-economic factors are rarely considered in as much detail as biophysical factors even in 'integrated' water vulnerability assessment tools (Plummer, de Loë, & Armitage, 2012, 2013). Recent work has identified the possibilities of developing complex models of 'socio-hydrology' (Elshafei, Sivapalan, Tonts, & Hipsey, 2014; Sivapalan et al., 2014; Thompson et al., 2013) and mapping socio-hydrological vulnerability across space and time (Boori & Voženílek, 2014). However, as Bitterman et al. (2016) highlight, complex human-environmental interactions, non-linear processes, and local geographies are all important considerations and often neglected when examining water security.

A recent systematic review (Plummer et al. (2012) identified at least 50 different integrated water vulnerability assessment tools, including measures of water security, water stress, water poverty, and water quality. The complexity of vulnerability assessment and water resources management has impeded the development of an agreed framework for understanding water vulnerability (Gain, Giupponi, & Renaud, 2012). However, even without an agreed conceptual framework, indicators are still commonly used to approximate or measure the various facets of vulnerability. Past work on water-related vulnerability has selected indicators to reflect aspects of the 'Driving force-Pressure-State-Impact-Response' (DPSIR) model (e.g. Argent, 2016; Bitterman et al., 2016; Hamouda, Nour El-Din, & Moursy, 2009; Varis, Kummu, & Salmivaara, 2012), the 'exposure-sensitivity-coping capacity' model (e.g. Alessa et al., 2008; Gain et al., 2012; Goharian, Burian, Lillywhite, & Hile, 2016; Nelson et al., 2010a), a combination of the two (Bär, Rouholahnejad, Rahman, Abbaspour, & Lehmann, 2015), conceptual models developed for specific geographic contexts (Pandey et al., 2010; Plummer et al., 2013), exogenous and endogenous stressors (Padowski, Gorelick, Thompson, Rozelle, & Fendorf, 2015), or simply the supply and demand for water within a region (Chang et al., 2013; Qian, Wang, & Zhang, 2014; Sullivan, 2011; Sun, Kuang, Xiang, & Che, 2016).

A common criticism levelled at vulnerability assessment is that it can be difficult to interpret and apply in a policy context, as the concepts involved are complex, and assessment tools may not address the needs of decision-makers (Hinkel, 2011; Nelson, Kokic, Crimp, Meinke, & Howden, 2010b; Vollmer, Regan, & Andelman, 2016). However, quantifying water vulnerability at the appropriate spatial scale can provide key information for generating effective adaptation responses and coping mechanisms for impending changes in water resources (Sullivan, 2011; Sullivan & Huntingford, 2009; Vörösmarty et al., 2010) although most assessments provide a temporally static snapshot of vulnerability, with even fewer including scenarios for future change. Past trends are infrequently assessed (a notable exception being Sun et al.'s (2016) water vulnerability assessment of the Yangtze River basin for the period 1994–2013), even though this could be useful in determining future trajectories.

As water supply and system demand is complex, measures of water supply should include all possible sources of water (including groundwater and soil moisture), rather than considering only precipitation, runoff and/or dam storage (e.g. Bolin, Seetharam, & Pompeii, 2010; Schyns, Hoekstra, & Booij, 2015). Conversely, water demand should take into account socio-ecological stressors influencing water use and needs (Bitterman et al., 2016). To this end, we attempt to address many of the concerns through the development of a robust water vulnerability assessment approach incorporating multi-scalar components of both water system supply and demand. The conceptual framework guiding the selection of appropriate vulnerability indicators was developed through expert consultation, is context specific, and incorporates socio-ecological stressors on the system. Data used to measure the various components of water system vulnerability are publicly available for transparency, replicability and ease of use, and persist through time allowing for an examination of past trends whilst providing a foundation for modelling trajectories. Our approach provides a transferable methodology that can be adapted and applied in a variety of geographic contexts.

2.1. Water vulnerability in Australia

Global-scale studies indicate that Australian drylands can be classified as vulnerable or at risk of water insecurity (Kok et al., 2016; Sietz et al., 2011; Vörösmarty et al., 2010). Aside from the Australia state of the environment report (Argent, 2016), there have been few detailed regional-level analyses concerning the vulnerabilities of both the water system and water users. There has been a national quantitative assessment of vulnerability of agriculture to climate change (Nelson et al., 2010a); qualitative assessments of risks to water supply security in surface water catchments (Preston & Jones, 2008); water vulnerability in urban areas (Werbeloff & Brown, 2011) and regional towns (Albrecht, Allison, Ellis, & Jaceglav, 2010); emerging research on water systems vulnerability in south-east Queensland (Sahin & Stewart, 2013); and much discussion of system sustainability in the Murray-Darling basin in eastern Australia (e.g. Connell & Grafton, 2008; Kandasamy et al., 2014; Srinivasan et al., 2012). Australia's exposure to the impacts of climate change was the impetus for a regional quantitative assessments of future sustainable water yields, primarily in areas of denser population and where irrigated agriculture is prevalent (CSIRO, 2008, 2009). By contrast, the Wheatbelt region of the state of Western Australia (WA) is sparsely populated with predominantly rainfed agriculture. The region has experienced a greater decline in precipitation than any other wheat-producing area in Australia (Asseng & Pannell, 2013), with further decline in precipitation expected (Hope, Drosdowsky, & Nicholls, 2006). Yet, there has not been a spatially and temporally detailed exploration of water system vulnerability for this area.