Advancing metrics: Models for understanding adaptive capacity and water security

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Abstract

We explore the relationship between water security (WS) and adaptive capacity (AC); the two concepts are connected because achieving the first may be dependent on building the second. We focus on how metrics of WS and AC are operationalized and what implications they may have for short and long-term management. We argue that rather than static conceptualizations of WS and AC, we need to understand what combinations of capacities are needed as a function of how controllable key parameters of WS are and the types of outcomes we seek to achieve. We offer a conceptual model of the relationship between WS and AC to clarify what aspects of human-water interactions each concept emphasizes and suggest a hypothetical example of how decision-makers may use these ideas.

Highlights

Water security and Adaptive Capacity are connected, especially in the face of future threats to water.

Combinations of capacities may be necessary to foster water security and avert water insecurity.

Metrics for water security and adaptive capacity have implications for management interventions.

Capabilities and pathways are key to understand the relationship between water security and insecurity.

New scholarship is needed to test how combinations of capacities shape water security outcomes.

Introduction

“Water security” (WS) and “adaptive capacity” (AC) are frequently associated with desirable outcomes in water management, especially concerning sustainable water access, use, and future availability [1-4]. But while both terms are seductive and usefully expressive of a desired outcome, they can also be problematic. The word “security” has been traditionally used to refer to safety from harm or disruption—such as natural disasters, disease, loss of income, crime, political unrest, or military threat [5]. AC, in turn, while around for decades [6-8], went from a panacea-like concept to a dimension increasingly criticized for the challenges related to empirically assessing it [9-11].

One way AC and WS interact relates to the threat of climate change on water resources —managing and reducing this risk may depend partly on building AC and developing indicators of the adaptation actions that have been taken to reduce water-related risks [12,13]. As these indicators inform current policy, we need to better understand how interventions that increase WS in the present may limit decision space for adaptation and transformations in the future [4,14]. Another way they interact refers to how metrics of AC and WS rely both on common and different parameters that have mostly assumed to positively feedback on each other while, in reality, they may tradeoff or detract from each other [1]. In this review, rather than assuming that all capacities are made equal, we suggest that different combinations of capacities may be necessary to foster WS and its desirable outcomes. Moreover, how we combine and measure these capacities has implications to the design and deployment of different types of interventions and approaches to development [13,14]. In the next sections, we review the literature focusing on WS and AC metrics, propose a theoretical model on how these two dimensions relate to each other, and offer an example on how they can be practically assessed to achieve desirable outcomes.

Defining and Measuring AC and WS

The IPCC AR5 defines AC as “the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond” [15]. In resilience studies, AC is the capacity of actors in the system to manage and influence resilience [16]. A dominant understanding of what influences AC is rooted in the IPCC’s historical categorization of AC as a suite of desirable ‘determinants’ that include economic and human resources, technology, information and skills, infrastructure, institutions, and equity [17]. And whereas various fields and disciplines have since expanded upon or refined this initial list [18-20], empirical metrics of AC have lagged behind theorizations of what it should be [11,21].

For WS, a widely accepted and frequently cited definition is: “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, environments, and economies” [22, p. 545]. For Scott et al [4], WS should not only include current societal and ecosystem resilience needs, but also consider these needs in relation to future global change (see also accompanying essay in this collection, “Context setting: Adaptive management & water security in key global regions.”). The limits of currently available interventions to deal with potentially uncontrollable impacts of threats, such as extreme events, have been highlighted in the adaptation literature, which increasingly calls for risk-based approaches that could better fit the potential for non-stationary and catastrophic thresholds as a result of climate change impact [12,23]. Scholars have called for a new development paradigm—Adaptive Development—that places risk front and center and fosters the idea of understanding combinations of capacities necessary to manage systems across risks (frequency, exposure, and preparedness) and interventions (institutional, incentive, and information-based) [13].

For both AC and WS, the development of metrics has been widely desirable as support for decision-making but contested in terms of: a) which indicators should be included and at what scale, b) how to measure them, c) how they feedback on each other and affect established institutions such as law and regulation, d) how actionable they are, and e) how well they represent the dynamic, non-stationary, and complex systems they seek to represent [1,12,21,24-26].

The literature on metrics of WS has emphasized two approaches: a) WS indexes [27-29], and b) a systems approach that identifies security with a *system state* in which sufficient water of acceptable quality is available to humans and the environment [30-32]. Research on indexes has focused on finding indicators that are relevant for end users [33], can be aggregated, and are replicable across systems or regions [34]. Systems approaches have been particularly concerned with determining relevant and measurable *key state parameters* that allow discerning systems' thresholds of insecurity.

For AC, while developing determinants-based indicators has dominated empirical work focusing on water [1,25], more recently, two alternative heuristics have emerged: a) the Adaptive Capacity Wheel, which directly assesses the role of institutions in shaping AC [19], and b) the Differentiating Capacities Matrix, which seeks to understand how combinations of different capacities (generic and specific) shape desirable and undesirable adaptation outcomes [14].

In both literatures, there has been a call for multidimensional, composite, and multi-attribute indexes that can provide holistic and comprehensive representations of socio-hydro-ecological relations. But such indexes are difficult to implement empirically and are limited in capturing competing perspectives and conflicts as well as addressing the unavoidable subjective dimension of WS and AC [1,34,35]. Metrics based on variables that characterize WS as a *state* are more promising in addressing the dynamic complexity that characterizes this type of system, but they are still limited in capturing the existence of multiple and changing boundaries and scales, cross-scale feedbacks, interacting physical and human drivers, causality, politics, and the power of human agents to shape the system [12,26,36]. Future scenarios and projections of global climate change can potentially multiply the unpredictability of socio-hydro-ecological systems dynamics, thus further complicating the production of reliable water-security metrics [36,37]. Alternatives to overcome the limitations of static metrics, which provide measurements at a specific point in time, emphasize risk-based indexes and approaches as a way of capturing the current situation and the potential consequences that may emerge in an uncertain future [13,14,30,37,38]. Some authors call for combining material and cognitive processes into a dual assessment of WS [39] and embedding qualitative data on the everyday experiences of users in WS indexes [28] (see also [26] for a general framework in this direction). For both WS and AC the conceptualization of a "pathways approach" that discloses sequences of path-dependent mixes of interventions (e.g., investments in institutions and infrastructure) and desirable outcomes (e.g. win-win, no-regrets approaches) that can potentially reduce water insecurity in the short and long term is particularly promising [12,40-42].

Water Security, Adaptive Capacity and Development.

Understanding the relationship between risk and development is increasingly recognized as key for adaptation [13,14,43]. In general, development is thought of as a desirable state or process to be promoted, while risk is dominantly understood as an undesirable factor to be managed and reduced. Yet, there are tradeoffs as certain forms of development may generate major risks and embracing some measure of risk can be crucial for opening up opportunities and, therefore, promoting development [43,44]. The y-axis in Figure 1 seeks to capture the degree to which the different approaches consider the interdependency between risk and development represented both by tradeoffs and synergies. This continuum has been explored in climate adaptation literature in terms of improving coping strategies versus changing development visions [45] and in terms of specific versus generic capacities and how they shape the ability of systems and communities to manage risk (14,44]. Thus rather than opposing dimensions, the y-axis suggests a continuum of relationships between opportunities and risk that lead to different outcomes shaping the ability of water systems to avoid undesirable states (water insecurity) and transition into more desirable ones (AC and development pathways). Below we offer a conceptual model of how different development paradigms may relate to the metrics of WS and AC (Figure 1).

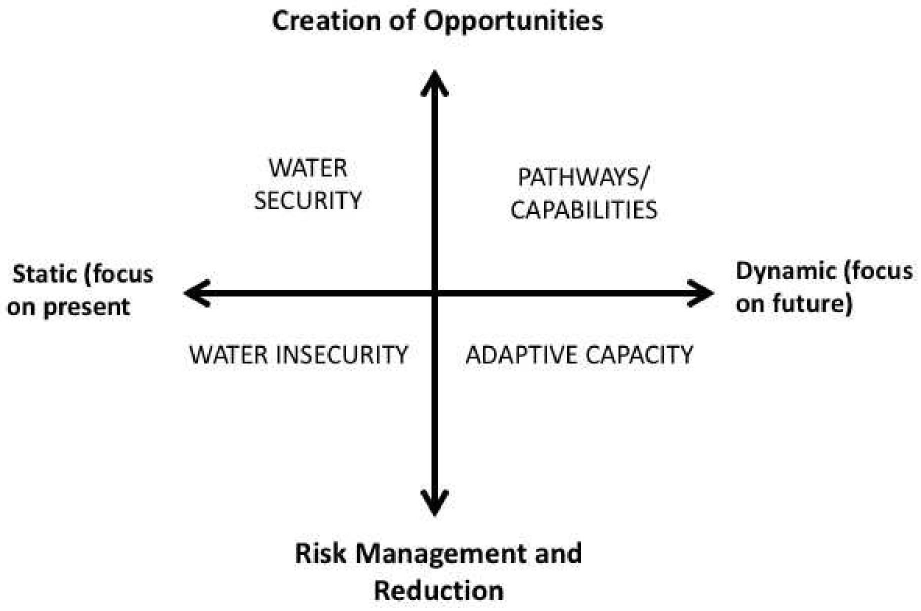

Figure 1 Conceptual model of the relationship between Adaptive Capacity (AC) and Water Security (WS).

Bringing Water Security and Adaptive Capacity together in practice

While the definition of WC suggests it to be a state (i.e. a system is either water secure or not), AC suggests ability to change from one state to the other with a presumption of progress from an undesirable state to a desirable one (i.e. from water insecurity to WS) [46]. In this conceptualization, the difference between the two states depends on whether certain parameters have passed or are below a certain set of threshold values [12]. Hence, WS is likely as long as there is control over certain key parameters that, for example, affect access to adequate quantities of acceptable quality water. Here AC may refer to the system's ability to control these parameters to avoid an undesirable threshold (e.g. bouncing back after a negative disturbance) and to move in a desirable direction (e.g. planned adaptation towards transformation). In this sense, we can categorize parameters across a range of controllability, that is, those over which agents can exert control (e.g. reducing the concentration of waste in waterways or storing water through the construction of reservoirs) and those that are beyond their control (e.g. extreme climatic events). This categorization allows us to draw the following two-dimensional representation of the Water Security/Water Insecurity phase diagram (Figure 2) where the horizontal axis corresponds to the beyond-our-control order parameters (e.g. climate variability, climate extremes, natural catastrophic events) and the vertical axis represents those other parameters agents (e.g. society, community, government, etc.) are able to control. 'Δ' refers to the controllability of the parameters, such that order arises when closer to zero.

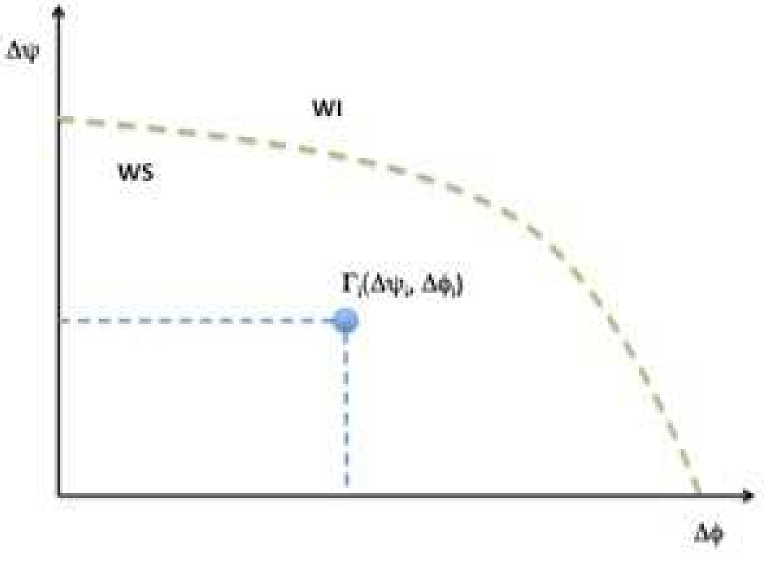

Figure 2 Two-dimensional representation of the Water Security/Water Insecurity phase diagram. The green line denotes the interface and each point is a particular state of the system, characterized by a set of metrics (Γ).

AC can be regarded as a measure of the actions (or potential actions) taken by actors to stay away from the Water Security/Water Insecurity (WS/WI) boundary (e.g., by improving the operational capacity of the water utility) or expand it (e.g., by constructing a water transfer system) as is represented in Figure 3. Here combinations of different capacities may allow actors to design and implement interventions (e.g. infrastructure, rules, adaptive management) that result in WS desired outcomes (i.e. that reduce the value of $\Delta\tilde{\Psi}$).

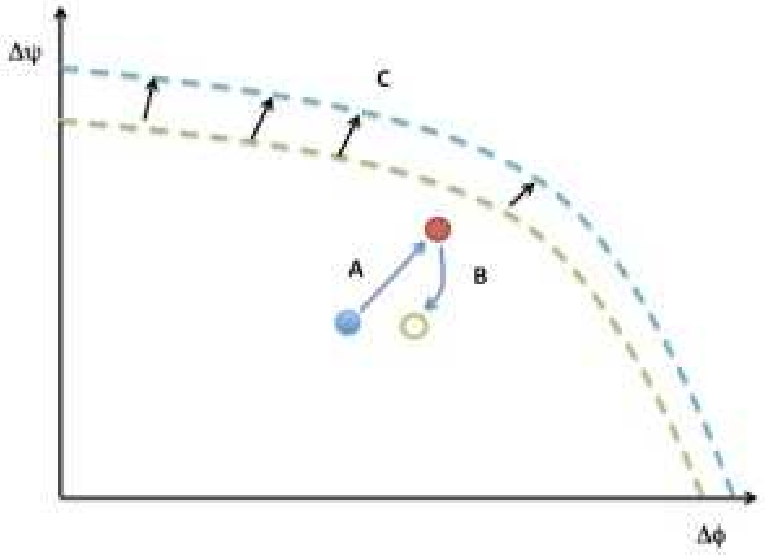

Figure 3 The system is perturbed and approaches the Water Security/Water Insecurity interface (A). AC is the bouncing back (B) and/or expansion of the Water Security/Water Insecurity interface (C).

However, practically, understanding how different capacities relate to WS key parameters is necessary to inform action. Below we offer a hypothetical application example of how this relationship can be assessed in the context of different desirable outcomes (Table 1). While reconciling net effects may be complex, understanding potential synergies and tradeoffs can provide decision-makers with a useful tool to assess the potential synergies and tradeoffs between different interventions relative to different outcomes.

Table 1 Assessing capacities, desirable outcomes, and tradeoffs

Indicators	**Level of control**	**Combination of Capacities**	**Desired outcomes**	**Potential tradeoffs**
Water quality	High-medium	Technology, knowledge, political will, financial resources, preventative regulation, management	Ecosystem health/restoration, human health,	
Water quantity by source	Low	Technology, infrastructure, redundancy, financial resources	Resilient cities, Productive agriculture Human and ecosystem health	Flexibility, adaptive management
Water quantity by location	Medium-low	Infrastructure, technology, financial resources	Resilient cities, productive agriculture, human and ecosystem health	Flexibility, adaptive management
Access to water/ allocation	High-medium	Infrastructure, equity, institutions (rules of the game), governance, social networks, co-management.	Resilient communities, human health, equitable distribution of water	Technocratic dominance, power differentials, participatory process vs. efficiency
Hazard/impacts	Low-no control	Disaster response, alert systems, infrastructure, technology, knowledge, flexibility, redundancy, adaptive management.	Resilient communities, sustainable adaptation, capacity for positive transformation	Maladaptation, overreliance on infrastructure and technology, flexibility vs. reliability, poverty/rigidity traps

Conclusions

WS and AC are intrinsically connected because achieving the former may be dependent on building the latter. However, while this relationship is often theorized, in practice, the operationalization of their intersection has been under-explored. In this review we propose a conceptual model relating the two concepts in terms of tradeoffs and synergies that can lead to different outcomes in the continuum of water security/insecurity. We also suggest an approach for developing a set of metrics that explicitly seeks to connect AC and WS by either avoiding undesirable thresholds or expanding them while taking into consideration that not all variables (e.g. climate variability and change) are controllable. While the practical application of these metrics has yet to be explored empirically, we believe that adding a dynamic dimension and recognizing that capacities/risks are not pre-determined but can combine and interact in ways that may lead to different outcomes could help decision-makers (e.g. water management and infrastructure) to better plan for an uncertain and non-linear future. It also suggests the need to think of metrics that avoid not only static representations of the future, but also of the relationship between risk and development.

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