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Metrics for assessing adaptive capacity and water security: common challenges, diverging contexts, emerging consensus

Gregg M Garfin[1,2], Christopher A Scott[3], Margaret Wilder[4], Robert G Varady[5] and Robert Merideth[5]

The rapid pace of climate and environmental changes requires some degree of adaptation, to forestall or avoid severe impacts. Adaptive capacity and water security are concepts used to guide the ways in which resource managers plan for and manage change. Yet the assessment of adaptive capacity and water security remains elusive, due to flaws in guiding concepts, paucity or inadequacy of data, and multiple difficulties in measuring the effectiveness of management prescriptions at scales relevant to decision-making. We draw on conceptual framings and empirical findings of the thirteen articles in this special issue and seek to respond to key questions with respect to metrics for the measurement, governance, information accessibility, and robustness of the knowledge produced in conjunction with ideas related to adaptive capacity and water security. Three overarching conclusions from this body of work are (a) systematic cross-comparisons of metrics, using the same models and indicators, are needed to validate the reliability of evaluation instruments for adaptive capacity and water security, (b) the robustness of metrics to applications across multiple scales of analysis can be enhanced by a 'metrics plus' approach that combines well-designed quantitative metrics with in-depth qualitative methods that provide rich context and local knowledge, and (c) changes in the governance of science–policy can address deficits in public participation, foster knowledge exchange, and encourage the co-development of adaptive processes and approaches (e.g., risk-based framing) that move beyond development and use of static indicators and metrics.

Addresses
[1] School of Natural Resources and the Environment, The University of Arizona, Environment & Natural Resources 2, 1064 E. Lowell St., N419, Tucson, AZ 85721, USA
[2] Institute of the Environment, The University of Arizona, Environment & Natural Resources 2, 1064 E. Lowell St., N419, Tucson, AZ 85721, USA
[3] School of Geography and Development, Udall Center for Studies in Public Policy, The University of Arizona, USA
[4] School of Geography and Development, Center for Latin American Studies, Environment & Natural Resources 2 Building, OFFICE S-419, The University of Arizona, Tucson, AZ 85721, USA
[5] Udall Center for Studies in Public Policy, The University of Arizona, USA

Corresponding author: Garfin, Gregg M (gmgarfin@email.arizona.edu)

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Introduction

Societal response to the global-change grand challenge must increasingly recognize diverse and mutually interacting drivers (climate change, extreme events, urbanization, and human-induced water scarcity, to name a few drivers) and gaps in the assessment of human and ecological vulnerability, the effectiveness of adaptation, and the robustness and equity of outcomes (here taken as water security based on the framing of this special issue). The introductory article [1] poses questions of (a) measurement of adaptive capacity and water security as well as the usefulness of their quantification at different scales, in diverse settings, and within various governance modes; (b) the implications for the robustness and quality of the knowledge produced by metrics; (c) the performance of metrics and assessment instruments; and (d) the accessibility and value of metrics and related instruments to practitioners and public stakeholders. Here we reflect on these challenges shared in common across multiple contexts globally.

Taken together, the papers in this special issue provide insights on — but do not fully resolve — common challenges of the assessment of adaptive capacity and water security. The authors in general take adaptation as a process in which individual, collective, and institutional capacities may vary but are subject to enhancement, or indeed, reduction. By conceptual contrast, water security is understood in normative terms as an end goal — a result or outcome of adaptation accompanied by sufficiently favorable conditions. No authors in this special issue consider the linkages between adaptation as process

and security as outcome to be static; that is, water security may ultimately be an elusive goal.

Adaptive capacity — water security linkages

A significant contribution of this collection of articles is to define the conceptual linkages between adaptive capacity (in water governance) and water security. This relationship is frequently implied in the literature but insufficiently examined. Yet the articles included here have distinct understandings of these key concepts. Four groups of authors [2–5] grapple with the inter-relationship of these. Kirchhoff *et al.* argue for the inter-dependency of the two concepts and understand adaptive capacity as a process on the path toward the goal of water security, where higher adaptive capacity is linked to more adaptive management and increased water security [3]. They make a case for building suites of capacity to deal with distinct challenges. They demonstrate the efficacy of adaptive capacity based on evidence from case studies in Argentina, Mexico, and the U.S.-Mexico border. Lemos *et al.* assert that the two concepts are connected because water security may be dependent upon adaptive capacity, but a more dynamic understanding of capacity is needed, one that (in keeping with [3]) emphasizes combinations of capacities (e.g., generic versus specific capacities) in a fluid policy making environment [5].

De Grenade *et al.* understand adaptive capacity in two ways, as it affects systems' vulnerability and capacity to respond to stresses and as it affects the resilience of social–ecological systems [4]. They argue that adaptive capacity needs to be better integrated into the water–energy–food nexus framework, with development of metrics instruments that embrace the nexus approach. In contrast, Varady *et al.* characterize adaptive capacity as 'a link between vulnerability and resilience frameworks,' while locating adaptive management as a governance approach concerned with managing risk and uncertainty [2]. Based on what they argue is greater empirical evidence, they view adaptive management as a more promising framework that provides for iterative and systematic experimentation in water management to address uncertainty.

Several articles argue for the positive value of metrics and assessment in the cases studied; several are skeptical or even critical of such approaches, deeming them of little value as currently designed and implemented. Virtually all the articles acknowledge a need for cross-comparisons that are facilitated by the use of quantitative measures, however imperfect; at the same time, most of the authors here are wary of approaches that may be overly-reductionist in simplifying complex problems. Overall, a 'metrics plus' approach that favors the development and use of well-designed quantitative metrics, coupled with in-depth qualitative methods that provide rich context and local knowledge, may on balance be the ideal.

Presently too little is known about how reliable or useful such instruments are. Thus, metrics and assessment instruments should increasingly be routinely tested and gauged for validity, robustness, and utility to enhance the reliability of these instruments and engender confidence in stakeholders and decision makers who may rely on them. Doing so may help enhance stronger index designs over weaker ones and encourage the use of more standardized approaches to index design. The special issue provides some evidence that practitioners and decision makers are increasingly reliant on metrics and assessments. But frequency of use does not necessarily suggest satisfaction with the metrics, and little is known about how metrics are used and employed. This dearth of knowledge suggests this is an area ripe for more research. Technological advances in GIS, mapping, and visualization have made metrics instruments more user-friendly, and scenario planning and other visually-based planning frameworks may be able to integrate multidimensional composite indices into public planning activities.

The importance of scale, uncertainty and context

Virtually all of the articles in this issue raise the problems of scale, uncertainty, and context with regard to metrics instruments. Romero-Lankao and Gnatz make a compelling case for developing metrics instruments to address urban water security [6]. While most indices are designed at a national scale, metrics approaches at the increasingly-important urban scale have lagged behind. They propose some adaptations of traditional indices approaches to correspond to the drivers and dynamics of urban water security. Thapa *et al.* shed light on a second analytical scale that is largely-neglected in the development of measures to assess water security and adaptive capacity, that of farmer-managed irrigation systems [7]. The authors offer insights on specific capacities to improve climate-risk management and generic capacities needed by small-scale irrigators to achieve long-term development goals.

Uncertainty about future states of the climate, water resources, environmental, and societal systems motivates concerns about selection, measurement, aggregation, and weighting of indicators of water security and adaptive capacity [2,5,6]. Conceptual understanding and incorporation of uncertainty is essential for the framing of integrated resource management and adaptation plans, and for social learning and scientific knowledge generated by surprises from the implementation of strategies [2]. Implicit in de Grenade *et al.*'s proposed expansion of the nexus concept to include society and the environment, is the examination of system change and dynamism, which, they argue leads to improved characterization and incorporation of uncertainties in management perspectives [4]. Similarly, Kirchhoff *et al.* and Lemos *et al.* note the importance of examining system dynamics and the time evolution of factors related to adaptive capacity and water

security, in order to understand current and future uncertainties [3,5]; Lemos *et al.* specifically point to risk-based approaches to identify and address uncertainties [5]. Scholarship that suggests actively 'embracing uncertainty' can form the basis for improved hypothesis testing, experimentation and construction of indices [2,6]; participatory approaches that embrace uncertainty can also shine a light on the dynamics and multidimensional aspects of water security [2]. Sun *et al.* make the important point that absolute water security cannot be achieved, as a result of the dynamism in the climate-society-environment system [8]; hence, relative and comparative measures, over multiple time steps, are needed to make the most of the water security concept. Sun *et al.* and other authors recommend methods, such as fuzzy mathematics or fuzzy logic in the calculation of water security indicators, to address uncertainty in estimates of future water security [6,8].

With regard to the potential promise of emerging quantitative metrics of adaptive capacity and water security, several of the articles in this collection take an agnostic, if not a critical, view. Nkhata and Breen find only limited benefits from such assessments, given the deeply-riven cultural and political contexts of water policy decision making in sub-Saharan African countries and, they assert, in developing countries of the global South [9]. Petit (Integrated Water Resources Management — IWRM) and Cook (drought management in England) each find that metrics in their respective cases are ill-conceived, too narrowly-wrought, and often are wide of the mark [10,11]. Petit argues that IWRM is at the centre of the firmament of international water policies, and yet points out that there is scant evidence to support the approach, due to the difficulty of measuring progress toward IWRM goals [10].

Cook finds that drought triggers constitute a kind of decision-making tool used to measure consumers' willingness-to-pay for drought management options. The article asserts that drought planning has thus become a proxy measure of public water supply security, yet an ineffective one [11]. Sun *et al.* chronicle a significant growth in the use of metrics and indicators in China to guide water policy decision-making [8]. Yet selection of appropriate indicators and aggregation methods pose challenges for such approaches, and integration of meaningful public participation continues to be an elusive goal.

Several articles discover more positive potential for such metrics in the cases they examine. Garrick and De Stefano find systematic assessments of water security for shared federal rivers very useful for comparing institutional design [12]. Yet, in what we might term a 'metrics plus' approach, they advocate for complementing metrics with in-depth case studies to capture local context, richness and diversity. Van Noordwijk *et al.* present the most positive evidence in this issue in favor of metrics approaches [13]. Their case of an agroforestry sustainability project in Indonesia and elsewhere in Asia provides evidence of successful use of 'ecological metrics' and 'human capacity' indicators to support socio-ecological resilience in the face of climate change.

Whither metrics and comparative assessment?

The papers in this special issue point to common challenges to the development and application of metric instruments, including an abundance of indicators, metrics, and methods; over-application of static and reductionist indicators; flawed or vague conceptual frameworks; scales of data and information that do not mesh well with the scales needed for decision-making; and inadequate public participation in the development and application of metrics. In the introduction to this special issue, Wilder referred to the lack of solid information on measures of adaptive capacity and water security as an adaptation information gap [1]. To overcome these challenges, and address the adaptation information gap, we recommend several paths forward, as follows:

- Governance of the science–policy interface can be designed to foster approaches that are more responsive to the needs of decision-makers and to the rigor of science. Through partnerships, and proactive management of the boundaries between researchers and practitioners, parties can co-produce adaptive approaches to the development, implementation, and evaluation of metrics, and to the management of resources and risks.
- Further research is needed to understand gaps in data, indicators, metrics, and evaluation methods. We recommend an approach that views the development and implementation of metrics as a dynamic and fluid process that evolves through time, insights, and new technologies. If static metrics are viewed as etched-in-stone absolutes, or one-method-fits-all panaceas, then scientists and society are guaranteed to fall short. Risk-based framing and assessment methods show promise for capturing current and potential future consequences, and for characterizing changes in uncertainty.
- Systematic experiments, using the same models, sets of indicators, and metrics, in cross-site comparisons, can be employed to evaluate the reliability, transferability and scalability of approaches.
- To address issues of scale, we recommend using nested sets of evaluations at multiple scales. Nested approaches could combine qualitative and quantitative indicators, in a manner appropriate to spatial and temporal scales. Incorporating a temporal element, for re-evaluation, is consistent with adaptive management and assessment of indicators. Mixed methods or *metrics plus* approaches can be used refine analyses and report on nuances not captured in generic, basin-, state-scale, or nation-scale indicators.

Lastly, given the critiques of somewhat elusive goals — such as water security, drought preparedness, adaptation to anticipated climate changes, or integrated resource management — patience and flexibility are required. We believe that a process designed for representative participation, social learning, and frequent re-evaluation will yield metrics from which we can learn and make decisions — imperfect, but evolving and improving metrics are what we can aspire to develop.

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