# Metrics: Moving beyond the adaptation information gap— Introduction to the special issue guest edited by Gregg M. Garfin, Margaret Wilder and Robert Merideth

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## Highlights

The development of quantitative instruments to evaluate water security and adaptive capacity is an emerging field of scholarship.

Metrics instruments include indices based on composite indicators, scenario planning, and geo-spatial visualizations and maps that allow comparisons across scales, space, and contexts.

Metrics development holds the promise to influence sustainable water policy, though challenges and barriers to successful application exist.


## Abstract

This introduction to the special issue addresses the need to move beyond the adaptation information gap and the benefits and problems inherent in this move. It provides a background on this project and a brief review of the existing literature and recent advances in developing measurement and assessment instruments—'metrics'—for the important guiding concepts of water security and adaptive capacity in water management. The review summarizes the promise and challenges encountered in the development and application of metrics and demonstrates that significant challenges remain in developing and applying metric instruments in real-world contexts, the most vexing being the lack of agreement on what model(s) to use and how to weight factors; the lack of evaluation of the validity and robustness of the instruments; the lack of consistency in analytical and application scales; deficits in engaging public participation in instrument design and use; and enduring tensions between contextualized and systematized knowledge, descriptive and predictive capabilities, and static and fluid data.

Key words: metrics, assessment, adaptive capacity, water security, vulnerability

Adaptive capacity and water security are concepts that guide how water is managed worldwide in response to climate change. Yet not only are these terms used in disparate ways for divergent purposes, they are context-specific, are employed at multiple analytical scales, and resist easy quantification and standardization. As new, soft-path, governance-centric framings for sustainable water management are introduced, decision makers are often unable to assess the effectiveness of the resulting approaches. Case studies of adaptation in water management do not enable comparisons across geographic, cultural, or institutional settings. For a scientific and policy community increasingly committed to 'data-driven' solutions, this lack of information may translate to a dearth of compelling evidence to influence sustainable policy decisions. While 'metrics' have the potential to obscure differences or may result in reductionist understandings of complex issues, quantification can be combined with qualitative methods to reveal dimensions of issues related to socio-political context, power imbalance, or social inequity [1,2*].

Calling for the development of a new climate adaptation paradigm, an influential report by the U.S. National Academy of Sciences concluded that adaptation is hampered by "*a lack of solid information about the benefits, costs, and effectiveness of various adaptation options*, by uncertainty about future climate impacts at a scale necessary for decision-making, and by a lack of coordination [3:1, emphasis mine]." We refer to this 'lack of solid information' as an *adaptation information gap*.

In response to this information gap, an interdisciplinary field of research has emerged directed at developing meaningful 'metrics' to assess or measure adaptive capacity and water security. There is a growing body of work on the elements and attributes of indicators that constitute adaptive capacity in water governance, yet there has been limited research on how to assess the existence, extent, and quality of adaptive capacity and water security. This special issue of *Current Opinions in Environmental Sustainability* on the metrics of adaptive capacity and water security synthesizes state-of-the-art knowledge on these concepts in water management including models based on indices and spatial visualizations. *In short, can adaptive capacity and water security meaningfully be measured? If so, can the resulting quantifications be useful at different scales, in diverse settings, and within various governance modes? What are the implications for the robustness and quality of the knowledge produced? How accessible are such metrics instruments to practitioners and public stakeholders in global regions?* These key questions motivated the articles presented in this issue. The special issue emerged from an October 2014 NOAA-funded workshop held at the University of Arizona (Tucson, Arizona, USA) on the metrics of water security and adaptive capacity in water management in the arid Americas, subsequently expanded to include diverse global regions and themes. This introduction provides a brief review of the existing state of knowledge. Gregg Garfin, Robert Merideth and I guest-edited the issue, and collaborated with other project leaders including Maria Carmen Lemos, Patricia Romero-Lankao, Robert Varady and Christopher Scott.

## The 'Metrics' of adaptive capacity and water security: an emerging research field

As countries, cities, and households around the world confront changes in environment, climate, and society, the common recipe for reducing vulnerability and risk is adaptation. A shared goal is planning how to adapt within the sector to achieve water security, related to a system's adaptive capacity. Adaptive capacity is a complex concept that has been defined in multiple ways [4], and is here understood as the ability of a social-ecological system to respond to and anticipate the effects of changes or stresses [4,5], based on access to technical, social, institutional, and other capitals. Adaptive capacity is key to achieving water security (see Kirchhoff et al. and de Grenade et al., this issue). Water security can be defined as "the availability of adequate quantities/qualities of water for societal needs & resilient ecosystems, in the context of current and future global change" [6]. At a time of growing demand for benchmarks, performance indicators, and output measures, our current inability to quantify adaptation and security impedes the adoption of promising new ways to frame resource-management processes.

The next section reviews metrics and assessment instruments for water governance and adaptation, in three categories: (i) vulnerability and poverty; (ii) water security; and (iii) adaptive capacity in water management institutions.

### Vulnerability and poverty instruments

Over the past two decades, indices and geospatial tools have been developed to map vulnerability using social, economic, and biophysical indicators and quantitative or mixed methods. A social vulnerability index simplifies the "multidimensional complexity of social vulnerability into a single metric" [7:527]. Often, indices are then used with geospatial data to create maps showing variations in vulnerability across a state or province, country or global region. Indices may use existing (biophysical or socioeconomic) data and/or may engage in developing new data through surveys, interviews, or focus groups. Methods may be 'top-down' (key indicators are selected by institutions or decision-makers based upon existing data) or 'bottom up' (local participants engage in classification process and contribute to the resulting maps).

Different measurement approaches yield distinct benefits, such as transparency about policy options but Roche et al. found no one model seemed suitable across the contexts studied [8]. Two reviews noted problems of definition and taxonomy; lack of comparable data; reliance on expensive or unfamiliar data collection processes; knowledge deficits; and the context-specific nature of many environmental problems [9,10].

The Social Vulnerability Index (SoVI) developed at the University of South Carolina [11] used 11 variables (e.g., wealth, age, housing stock, race, ethnicity) to map social vulnerability to environmental hazards, and was able to explain 76.4 percent of the variance among all U.S. counties. SoVI has been applied to urban vulnerability in the Greater Lisbon (Portugal) metropolitan area [12] and to coastal social vulnerability in Australia [13]. In the U.S., it has been used by policymaking organizations to examine vulnerability to extreme heat (e.g., Centers for Disease Control BRACE Project, at http://www.cdc.gov/climateandhealth/brace.htm). Stakeholder engagement has grown in recent decades to be a staple of vulnerability assessment and adaptation planning, leading to increasing sophistication of ‘participatory methods’ and mixed methods employed in metrics development (enabled by technological and computing advances over the same period), including qualitative interviews, ethnographic data and scenario planning [14,15].

What can we conclude about *how well* vulnerability indices and maps perform? Little is known about the reliability of social vulnerability indices and uncertainty is evident in indicator selection, analytical scale, data transformation, measurement error, normalization and weighting [4,7]. Tate’s analysis suggests that precision of social vulnerability index instruments decreases as vulnerability increases [7]. Of 25 vulnerability indices included in his analysis, Tate found a high degree of statistical bias, high magnitude of uncertainty, and less precision as vulnerability increased, owing in large part to variation in choices made about how to weight indicators in different models [7]. Tate concludes that social vulnerability indices must begin to standardize the application of uncertainty analysis to determine the robustness and reliability of an index instrument, meaning that minor changes in the construction of an index would not produce major changes in output metrics [7]. Of the over ninety percent of the studies in a comprehensive review [16] of 45 assessment studies that mapped climate vulnerability, most centered on understanding climate risks and identifying hotspots; only nine percent of vulnerability maps were linked to decision-support for adaptation. Cross-cutting challenges of vulnerability mapping, included the lack of a standardized methodology or best practices; incompatibility in spatial and/or temporal scales; deficits in stakeholder participation; and inadequate representation of uncertainty in the vulnerability assessment, calling into potential question the validity and robustness of the maps and data [16]. They noted an unresolved tension between the diagnostic and predictive capabilities of vulnerability maps, and a similar tension between 'holistic' visualizations of vulnerability based on multiple analytical/data scales and 'reductionist' models emphasizing vulnerability within a single parameter [16]. A separate review of water security assessment identified a lack of inclusiveness of low-income, marginalized populations, barriers in translating goals into policy, and over-emphasis on demand side analysis relative to supply [17]; see also Varady et al., this issue.

Water resources and water security instruments

Beyond instruments to measure social vulnerability to environmental hazards, strides have been made in specifically assessing water resources vulnerability and water security with quantitative metrics. The U.S. National Oceanic and Atmospheric Administration (NOAA) in 2016 rolled out a comprehensive "water resources dashboard" (http://toolkit.climate.gov/topics/water-resources/water-resources-dashboard) that integrates climate-and-water resources data and includes a Social Vulnerability Index tool (http://svi.cdc.gov/) with data and mapping capabilities to link social vulnerability to disasters, disease outbreaks, and human health. Still, no single model has emerged as a preferred approach and indices remain highly context-specific. Water vulnerability tools have been applied primarily in North America, Asia, and Africa and most are developed for national or watershed-scale analysis [18]. In a review of 50 studies with a total of 710 indicators, Plummer et al. found easier-to-define water resources indicators (e.g., water supply, volume) accounted for 45 percent of the total while institutional and social indicators of vulnerability (e.g., more resistant to standardization) represented less than 7 percent of the total [18]. Examples of the most comprehensive assessment tools include the Freshwater Related Indicators Inventory of Canada, the Water Wealth Index, and the UN Millennium Development Goals.

The Water Poverty Index [19] was developed as an accessible, transparent tool to enable monitoring of progress toward development goals in poor countries and improve equity in water allocation. Its goal was to quantify water poverty into a single number based on a standard five composite indicators (resources, access, capacity, use, and environment) [19,20]. The WPI employs proxy measures for each indicator; capacity, for example, is comprised of subcomponents that are measurable, such as “under-five mortality” and “educational level” [20:194]. The WPI has been applied worldwide, particularly in low-income pockets of the global North (i.e., west Texas) and in the global South (e.g., China, Kenya, Indonesia, Cambodia) and has given rise to multiple efforts to redefine and/or improve on the initial design of the index, for example, to incorporate agricultural water and climatic conditions [21] or to “open up” the concept to a co-production of knowledge framework reframing it as a “water prosperity index” [22].

Giné Garriga and Pérez Foguet determined that the WPI has “great relevance in policy making” but exhibits “conceptual weaknesses” including inadequate techniques used to combine data and problems with statistical properties in the resulting composite score [23:1287].

Garrick and Hall [24**] zeroed in on risk-based assessments of water security, capable of assessing both acute and chronic risk using composite indices. Risk is comprised of hazards, exposure, and vulnerability, and although risk is not observable per se, component factors can be quantified. Risk frameworks are employed by many organizations, including the Organization of Economic Cooperation and Development and World Health Organization. They reviewed instruments including water security and water vulnerability indicators, and multidimensional composite indices, and conclude that the "tools of risk analysis and management are well established" and can aid in developing adaptation pathways that lead to water security by identifying institutional capacity and investment gaps and needs [24**].

Adaptive capacity instruments

This emerging research in adaptive capacity metrics highlights the central role of governance in achieving water security. A common objective of the indices is to define key capacities (e.g., leadership, shared vision, trust, sustained relationships) needed by governance actors (e.g., federal, state, and local governments, irrigators and water users, civil society organizations) and to measure to what degree such capacities are present with a goal to identify gaps for investing and building capacity. The measurement of adaptive capacity is in its infancy. Nevertheless, some significant efforts have been made to develop multidimensional indices to quantify institutional adaptive capacity. For example, Grothmann et al. [25] and Gupta et al. [26**] developed an adaptive capacity 'wheel' or index based on indicators such as social learning, leadership, and fair governance. Milman et al. [16] pioneered an index-based approach using governance indicators to measure transboundary adaptive capacity in the Middle East and Mediterranean. Engle and Lemos [28] constructed a river basin index to characterize governance approaches in Brazilian river basins, applied a reliability test to assess the validity of these governance indicators, and used in-depth qualitative data collected in a subsample of the basins to explore the relationship between the governance indicators and adaptive capacity. Clearly these indices offer similar benefits (e.g., facilitate comparison across countries and contexts) and suffer from similar challenges (e.g., utilize different models, weight indicators differently) as in the other categories of indices reviewed here.

## Discussion

This short review of the evolution of metric instruments points up the key benefits and barriers (summarized in Table 1) to understanding and representing water security and adaptive capacity, and begins to answer some of the questions posed at the beginning of this introduction—questions that are also taken up by the contributions to this special issue. We find evidence that the desire for systematized ways of understanding water-related vulnerability and the development of metrics is increasing in water research with more sophisticated methods and analysis. Agencies and policy makers have begun to develop, adopt and broadly use such instruments. But this review demonstrates that significant challenges remain in developing and applying metric instruments in real-world contexts, the most vexing being the lack of agreement on what model(s) to use and how to weight factors; the lack of evaluation of the validity and robustness of the instruments; the lack of consistency in analytical and application scales; deficits in engaging public participation in instrument design and use; and enduring tensions between contextualized and systematized knowledge, descriptive and predictive capabilities, and static and fluid data.

In this collection, the editors have invited new contributions to illuminate emerging metrics models and applications in water security and adaptive capacity in water management. We remain committed to the quest for useful measures, and the value of the knowledge generated through critical analysis. Focusing on a dozen themes ranging from conceptual frameworks to applied analyses, 37 expert authors from 23 institutions in over a dozen countries contribute.

Varady et al tackle a fundamental problem—highlighted by the challenges of assessment of the UN's Sustainable Development Goals--that many suggest as an impediment to developing standardized metrics of assessment, that is, lack of standardized definition of core concepts. Adaptive management emerges as key to notions of developing adaptive capacity toward achieving water security. The ability to quantify change is essential to the work of social learning for adaptive management, and the stakes of doing so are promising, yet elusive.

Romero-Lankao and Gnatz examine the role of metrics in assessing urban water security using a SET*E*G framework, arguing that improved selection of indicators for the five framework goals would enhance urban water security. As the world's major cities grow, how can metrics help identify and address key global challenges of urban areas?

Kirchoff et al. examine the interdependencies between adaptive capacity and water security and develop a theoretical model linking these core concepts. In the context of arid regions in Argentina, Mexico, and the U.S., they argue that insufficient local capacity impedes achievement of water security and 'transformative' adaptive capacity should become a regular ingredient in the water security recipe with appropriate assessment measures.

De Grenade et al. take on the challenge of addressing metrics in the water-energy-food conceptual nexus. They underscore the role of environment itself in shaping the WEF nexus, and suggest fruitful paths to explore in developing a standardized set of metrics that could assess the WEF nexus across multiple scales.

Lemos et al. focus on how the metrics of adaptive capacity and water security are operationalized, and with what implications for water management. They direct our attention to the fluid capacities of these two concepts rather than static definitions, arguing for the enhanced efficacy of risk-based and pathways approaches that avoid utilizing static moment-in-time metrics.

Garrick and DeStefano examine the role of institutional design in affecting the adaptive capacity of federal rivers. They argue that, while indicator-based inventories are useful, they must be supplemented with in-depth case studies in order to provide context-sensitive assessment.

In China, Sun et al. discuss the use of composite environmental-social-ecological metrics to assess the country's progress towards water security. While the assessment receives high marks in many respects, resolution of indicator-related issues and public participation are persistent challenges.

In a careful analysis, Nkhata and Breen argue that adaptive capacity assessments are of limited value in sub-Saharan Arica and other developing countries, although some context-specific assessment measures may be fruitful. While science can contribute to elucidating adaptation options and explaining environmental uncertainties, the act of making policy decisions is inevitably political and embedded in particular cultural contexts, rendering the assignation of numerical scores based on composite measures a technical exercise, devoid of meaning outside a socio-political context.

Petit offers a critique of the 'nirvana' concept of Integrated Water Resources Management (IWRM) based on experiences in applying metrics to measure IWRM progress. Noting that IWRM progress measures often falter, particularly in the context of water resources shared by multiple countries, Petit concludes that IWRM is a "paradise which has lost its way."

Cook examines drought planning in England as a proxy measure of public water supply security. Drought triggers developed by water service providers use market mechanisms as a tool to guide decision making. Cook finds such efforts inadequate to achieve water security as they have led to an emphasis on supply over demand management. Cook argues that a twin track approach privileging both supply and demand management and interpreting 'water security' more broadly would yield more sustainable results.

Thapa et al. analyze adaptive capacity in the context of farmer-managed irrigation systems, using case studies from Nepal. Based on a differentiation of generic and specific adaptive capacity indicators, the authors make a case for fine-grained understanding of adaptation processes in the context of small scale irrigation of particular importance in the global South.

Van Noordwijk et al. demonstrate a metrics ‘success story’ in Indonesian agroforestry, a project that combines ‘ecological metrics’ with human capacity measures to build a resilient socio-ecological system.

As a whole, this collection of articles constitutes a fresh and compelling evaluation of the theoretical and applied value of the emerging endeavors to develop metrics to assess water security and adaptive capacity in a dynamic era of water management innovation.

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Table 1. Summary of benefits of and barriers to developing metric instruments for adaptive capacity and water security

| Benefits | Barriers |
|---|---|
| Aid comparison across geographic contexts | No dominant accepted model, method, or weighting system |
| Can incorporate multiple methods (e.g., top-down and bottom-up; census and ethnographic data) | Developed and applied at different scales. Analytical scale used may obscure cultural & geographic differences |
| Provide decision-makers clear information on water-related risks | Reduce complex information to a single quantitative metric |
| Well-established as a diagnostic tool (e.g., identify vulnerability levels) | Lack predictive capacity |
| Increasingly applied in real-world policy making | Useful to identify problems but limited for making decisions on solutions |
| Geo-spatial analysis can produce maps with clear visual representation of the metrics | Lack of standardized evaluation of the performance/reliability of different instruments |
| Development of metrics instruments can engage stakeholders in design & implementation | Low-income, marginalized groups often left out of metrics development & implementation processes |