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A systems perspective on water markets: barriers, bright spots, and building blocks for the next generation

Dustin Garrick[1,2,*], **Soumya Balasubramanya**[3], **Melissa Beresford**[4], **Amber Wutich**[5], **Gina G Gilson**[6], **Isabel Jorgensen**[1], **Nicholas Brozović**[7], **Michael Cox**[8], **Xiaoping Dai**[9,10], **Sophie Erfurth**[6], **Renata Rimšaitė**[11], **Jesper Svensson**[6], **Julia Talbot Jones**[12], **Hita Unnikrishnan**[13], **Charles Wight**[6], **Sergio Villamayor-Tomas**[14] and **Karla Vazquez Mendoza**[15]

[1] University of Waterloo, Water Institute and School of Environment, Resources, and Sustainability, Waterloo, Canada
[2] University of Oxford, Green Templeton College, Oxford, United Kingdom
[3] World Bank, Environment, Natural Resources and Blue Economy Global Practice, Washington, DC, United States of America
[4] San Jose State University, College of Social Sciences Department of Anthropology, San Jose, CA, United States of America
[5] Arizona State University, School of Human Evolution & Social Change and Center for Global Health, Tempe, AZ, United States of America
[6] University of Oxford, School of Geography and the Environment, Oxford, United Kingdom
[7] Daugherty Water for Food Global Institute at the University of Nebraska and Department of Agricultural Economics at the University of Nebraska-Lincoln, Lincoln, NE, United States of America
[8] Department of Environmental Studies, Dartmouth College, Hanover, NH, United States of America
[9] North China University of Water Resources and Electric Power, Agricultural Water Management, Zhengzhou, Henan, People's Republic of China
[10] Hohai University, College of Agricultural Science and Engineering, Nanjing, Jiangsu Province, People's Republic of China
[11] Daugherty Water for Food Global Institute at the University of Nebraska and National Drought Mitigation Center at the University of Nebraska-Lincoln, Lincoln, NE, United States of America
[12] Te Herenga Waka—Victoria University of Wellington, School of Government, Wellington, New Zealand
[13] The University of Sheffield, Urban Institute, Sheffield, United Kingdom
[14] Autonomous University of Barcelona, Institute of Environmental Science and Technology, Bellaterra, Barcelona, Spain
[15] The Nature Conservancy, Arlington, VA, United States of America
[*] Author to whom any correspondence should be addressed.

E-mail: dustin.garrick@uwaterloo.ca

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1. Introduction

Water markets are a decentralized approach for allocating water and water rights that have been touted as part of the future of water policy for decades [1–3]. While proponents have lamented their slow uptake and critics have resisted their spread, water markets are neither new nor rare. Water trading in the irrigation systems of Oman and Spain [4, 5], for example, has occurred for hundreds of years, and evidence of trading in Australia and the USA has been traced to the 19th century. Even regions with relatively abundant water rely on tanker water markets and other water entrepreneurs to address shortfalls of labor and infrastructure [6–8]. The diversity of water market activity is illustrated by the nearly $2 billion (Australian Dollar) average annual turnover in Australia's surface water markets [9] or the tanker markets in Kathmandu which deliver approximately 20% of the water used by households in the dry season [10].

Despite growing experience, discussions of water markets are often dominated by myths rather than evidence [11]. Research is splintered by competing definitions and assumptions, constraining the consolidation of theory and practical insights for policymakers [12]. Water market proponents highlight their potential to address diverse policy objectives by allocating water efficiently and enabling adaptation to shifting patterns of supply and demand. Policy objectives range from reducing groundwater overdraft and restoring environmental flows to broader social and development goals, including poverty alleviation, sustainable urbanization, agricultural risk management, and meeting the human right to water. In contrast, critics note how water markets can cause negative impacts on communities where water is bought and sold and can further sideline or exclude Indigenous peoples by reinforcing legacies of colonization and dispossession that have limited formal allocation of rights [13–15].

The theoretical advantages and disadvantages of water markets have been debated for decades, leading to a growing call to 'go beyond blanket statements of whether markets do, or do not 'work', and are or are not exploitative' [16, p.9] by paying attention to the

empirical evidence and 'details on the ground' in a structured way. The diversity of water markets, ranging from tanker trucks selling water locally to long-distance rural-to-urban transactions, makes the accumulation of such evidence challenging but also more important.

A systems perspective on water markets can help scholars and policymakers identify the conditions under which water markets achieve their intended policy and development objectives and how they interact with other policies and incentives. In this paper, we bring together anthropology, economics, environmental science, hydrology, and public policy to better understand the diversity of water markets and motivate an interdisciplinary agenda. We focus on drivers of water markets, how they vary, and their dynamics and impacts in the context of broader social-hydrological systems. This fits with recent efforts to apply systems thinking to various forms of markets and value chains from fisheries to food systems, enabling a more holistic view of markets that reveals complex interdependencies and feedbacks, as well as processes and linkages that connect markets with broader systems [17].

A systems perspective can lead to 'more realistic models…[that] increase both the rigor and relevance of future research' [18, p.260]. A systems perspective can draw attention to the focal variables, interactions, and outcomes relevant for different water markets. Instead of imposing a single framework or typology, we contribute a systems perspective which is compatible with multiple existing frameworks and can enrich and strengthen them. Regardless of the framework selected, a systems perspective draws attention to complexity and context in a structured way, breaking water markets into several interacting elements: the sources of water and drivers of scarcity, the goods and services traded, the actors participating, the governance arrangements and property rights for allocating and reallocating water, and the interactions and outcomes at different scales and for different actors.

In the next section, we look back on the past 15 years of interdisciplinary research on water markets with a primary focus on conceptual issues and measurement problems hindering the accumulation of knowledge and policy insights. We then identify bright spots of progress in overcoming these challenges from an interdisciplinary perspective. We conclude with building blocks for the next generation, including priorities for research and practice for the next 15 years and beyond.

2. Barriers: *No shared definition of water markets; invisible informal markets*

Despite differences across disciplines and regions, definitions of water markets converge on the decentralized exchange of property rights, both formal and informal, to water-related goods and services within a given social-hydrological system [12]. Necessary conditions include scarcity, which need not be limited to water scarcity, and differences in the marginal value of water (or labor and capital for delivering it), which makes trade mutually beneficial for the buyer and seller. Water markets often rely on price signals to communicate the scarcity of water and its opportunity costs in competing uses, but may also overlap with other forms of exchange, such as gifts or reciprocal practices [6]. Engineering and economic studies focus on the ability to trade as a defining feature, along with assumptions that agents will maximize the utility or reliability of their water supply [19, 20].

Institutional differences make it difficult to classify water markets across contexts. As recently as 2019, two reviews of water markets reached conflicting conclusions, one noting that water markets are rare [21], while the other noting their proliferation and persistence [22]. Technically, both are right. Formal water markets (regulated by governments) remain rare, while informal markets (governed by locally crafted rules and norms) are widespread. There are increasing examples of overlapping water markets with rules crafted at different levels of governance. Despite their prevalence, informal water markets remain largely invisible (See figure 1). Though their illegibility defies standardized tracking and measurement, efforts are underway to better account for unregulated trading activity in the context of fisheries, land grabbing, and a range of illicit, illegal, and/or informal settings [23]. Not only has there been a failure to recognize and distinguish different types of water markets, but disciplinary studies offer a partial view that may neglect the structural factors, historical legacies, and other antecedent conditions that shape the emergence of water markets, their evolution, and impacts.

3. Bright Spots: *Measurement advances capture complexity, but are not comparable*

In a 2006 review of water markets and trading, Chong and Sunding [24] argued that 'putting water markets into practice introduces real-world complications' (p.39) that deserve growing scrutiny. Doing so has required advances in measurement, modelling, and management that show promising trends in a vibrant, but uncoordinated, body of scholarship. We focus on *bright spots* of interdisciplinary research on water markets in the period since their review. A systems perspective can highlight new connections across these bright spots to generate a new interdisciplinary field of research on water markets, with comparable datasets for assessing their evolution and performance, and insights for policy and practice.

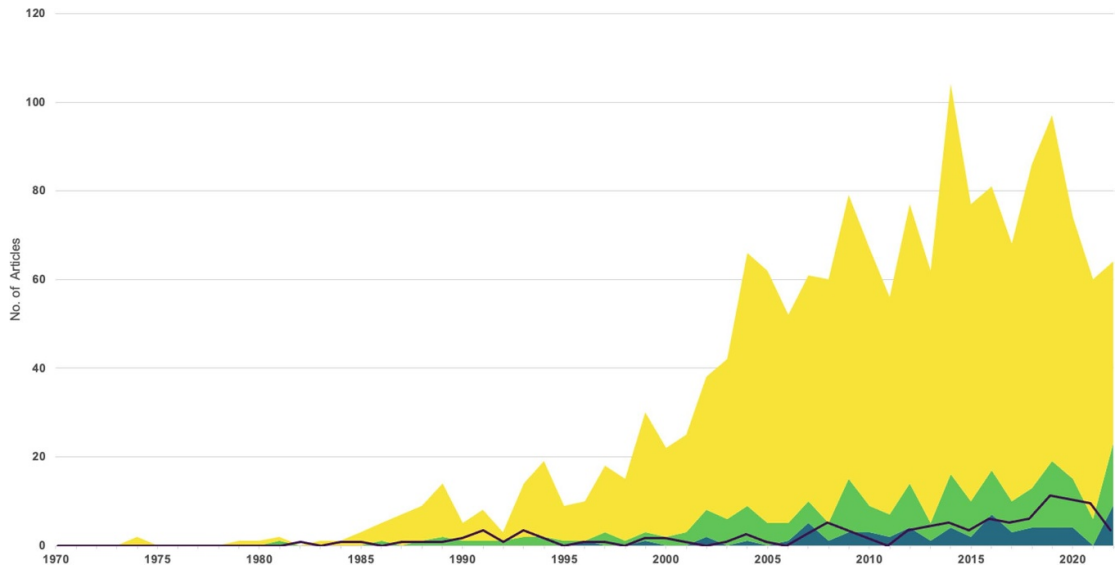

Figure 1. Articles on water markets illustrate that explicit attention to informal water markets and water vending remains rare. Data: Stacked chart of Scopus query on 15 September 2022 (article title, abstract, keywords) using search terms: 'water market' (yellow), 'water market' AND informal (green), 'water market' AND groundwater (blue), and 'water vend*' (line).

3.1 Measurement

Advances in measurement involve empirical studies that integrate previously disconnected datasets about the evolution and performance of water markets through interdisciplinary and longitudinal studies. Several empirical studies trace the effects of differences in institutional and policy approaches on market participation and outcomes over the long-term (i.e. over 10 years). Survey and archival data generate original datasets of water transactions, documenting the volume, price, location, and characteristics of buyers and sellers, including the types of farms, water vendors, and other actors selling water in markets. Ethnographic methods, including long-term participant-observation and interviews, generate hard-to-access data on cultural norms and lived experiences, particularly for informal water markets [6]. The most promising bright spots involve bringing together qualitative and quantitative data in a spatially explicit and system-wide way. For example, an international team from Kathmandu conducted a rare repeat study of water vending to develop a system-wide picture amidst changes in urbanization, water availability, and infrastructure coverage [10]. Farmer surveys of market participants from Australia to Algeria have generated insight about irrigator behavior in the face of shifting incentives created by markets, including the determinants of water sales, farm exit, and mental health impacts [9, 25]. Experimental and quasi-experimental research designs have enabled causal inferences about the effects of different policy levers and technologies, such as in West Bengal, where farmers who owned electric pumps sold more water to smallholders than farmers who owned diesel pumps due to cost differences across technologies [26]. In the last few years, studies from several US water markets have used micro-level trading data to estimate the environmental performance of water market transactions [27, 28].

Comparative research has also demonstrated how cultural differences in norms of justice and fairness shape acceptability of water markets [6], how legal conditions affect their suitability [29] and how individuals and communities have balanced benefits and risks of participating in markets [25]. These trends have coincided with efforts to broaden performance measurement beyond important economic studies to account for a range of impacts and outcomes related to justice, sustainability, and health.

3.2. Modelling

Advances in modelling include efforts to assess market potential and design through a suite of theoretical, mathematical, and simulation models that increasingly account for complexity. Interdisciplinary frameworks (i.e. hydro-economic and social-hydrological systems) coupled with access to low-cost datasets have enabled more complete and realistic models, and examine a range of assumptions around human behavior and policy settings. The work by Pujol and colleagues [30] is a point of departure, offering a theoretical framework that accounts for transaction costs in optimization studies to assess how market frictions can constrain gains from trade [28]. More generally, hydro-economic models have integrated historical datasets to assess the responsiveness of water markets to scarcity and shocks. The spatial resolution of modelling has increased for a finer-grained assessment of trading and its externalities, particularly in the context of groundwater markets that may need to be tailored to complex hydrogeological interactions [31].

Despite limited geographical scope of time-series data on water markets, creative approaches to causal inference (i.e. natural experiments, propensity score matching) are being deployed to assess the effects of policy instruments on investment decisions, water sales, productivity, and equity. Attention to informal water markets in systems modelling studies [34], although uncommon, has examined the interaction between piped water networks and tanker water vending to understand the drivers of vending activity amidst infrastructure and service delivery gaps from Chennai to *colonias* along the US-Mexico border [11].

3.3. Market design

Advances in measurement and management have generated new insights about market design. In the context of water markets, this has traditionally focused on issues related to allocating water rights and designing market clearing mechanisms (such as spot markets or auctions). Although conventional economic theory focuses on exclusivity, enforcement, and transferability, rights can range from formal systems of legal rights to informal arrangements relying on unwritten social norms and traditions [6, 10, 22, 32].

A systems perspective on market design requires attention to at least two types of institutional development related to the design of the market itself as well as a broader set of foundational and general considerations [33]. In the case of market-specific considerations, the conventional focus is on the allocation of rights and the development of trading rules and management of conflicts. In terms of the foundational elements and general considerations, a systems perspective draws attention to basic water accounting and different types of impacts, including the spatial and temporal considerations that tracks the impacts of markets locally, at present, and into the future [33–35]. In addition to its focus on policies, rules, and rights used to establish water markets, market design also addresses the externalities (unaccounted costs and benefits) that affect a range of third parties, such as effects on return flows or consequences for regional economies. Political and social safeguards include limiting water exports, community monitoring, and conflict resolution mechanisms. Such safeguards are increasingly coordinated across sectors and levels of governance as water moves longer distances and growing competition increases the interdependence of different water users. In other words, the cascading impacts of water trade have exposed the growing interconnections across sectors and scales and the need for policies and institutions to address third party effects and system-wide impacts on regional development. Trends toward more interdisciplinary analyses have highlighted the importance of production relations (whether sellers are independent or part of a group), group-level property rights (who has decision-making rights, particularly around the approval of trades), and policy levers in other sectors which influence market participation and performance (e.g. via energy pricing or agricultural subsidies) [36].

4. Building blocks: *Using systems thinking to build a global network of observatories*

Despite major strides, research on water markets is struggling to address the most basic and important questions: Why do different types of water markets emerge where they do? How and why do they vary? Do they work? If so, for whom and on what terms? A systems perspective can help to address these questions by bringing multiple disciplinary lenses together to capture different elements of water markets often examined separately, and to track these features of water markets consistently across geographies.

First, what drives the development of water markets? A systems perspective focuses on the institutions, external factors, and historical legacies that together shape the emergence and evolution of water markets. Hydrologists, engineers, and systems modelers assess the potential for markets in the context of different water management problems, while historians and policy scholars trace how markets come into being through case study research that attends to structural conditions whereby markets become the preferred solution. Both offer a partial perspective. By focusing holistically on the drivers of scarcity—and the characteristics of different water systems, uses, and users—it is possible to distinguish markets based on their functions and fit with local context [37]. A systems perspective also highlights the interconnected systems that shape water markets (e.g. agriculture, energy, and urban transitions) and their nested externalities (e.g. third party effects on rural development).

Second, decades of research have shown there is no one-size-fits-all solution to water challenges. There are multiple ways to create and govern water markets, including who can participate, which trades can occur, and how conflicts are resolved. Diagnostic approaches have been used to make sense of this institutional diversity and the recurring patterns. 'Readiness' assessments increasingly track factors expected to facilitate water trading [40]. Such approaches must account for multiple possible configurations of enabling conditions, rather than promote a universal set of necessary conditions. For example, in the case of China's water trading reforms, multiple pathways can lead to trading from agricultural to urban users [41]. Cataloging institutional diversity can identify which different approaches are likely to work or not in different contexts, including the policies, incentives, and other factors that condition their performance.

Finally, a systems perspective requires researchers to move beyond economic efficiency when assessing

Table 1. A systems perspective on data collection priorities for water transactions.

Definition	Selected data collection priorities	Measurement challenges	Recommendations
Transaction An exchange of water-related goods and services, often in response to price signals (following [38])	Physical and natural dimensions What is the *source* of water? Which *water-related goods and/or services* are traded? How are they *conveyed* from seller to buyer? Human and institutional dimensions *How much* is traded at what price over what time period? What are the *transaction costs* of trading? Who buys and sells water, and how are they organized? What local, cultural, or situational rules and norms shape the transaction? Interactions, impacts and outcomes How are people and ecosystems affected by trading activity at multiple scales?	• Lack of standards, priorities, and protocols for transactions data • Inadequate metering at farm level to monitor water use and trade • Lack of centralized and long-term databases or trading platforms • Partial coverage of historical record, qualitative data, and of informal transactions • Stigmas, danger, and difficulty of collecting data on informal water markets • Challenges with (dis)aggregating transactions data to examine spatial and temporal trends and to identify distributional impacts	"Quick Wins" • Use existing trading platforms for low-cost monitoring of trading activity. • Leverage agricultural census and other data collection activities for questions about participation in water markets. "Best buys" • Establish ISO-like standards for transaction accounting. • Compile transactions through surveys of market participants across sites and over time. • Generate case study databases to facilitate collation and comparison of qualitative and historical data "Game Changers" • Establish observatory network guided by shared protocols.

Note: The terminology regarding 'quick wins', 'best buys' and 'game changers' comes from the UN 2022 Roadmap for Covid-19 Recovery [39, pg. 23]. These categories were used in that context to identify research priorities and classify them based on the timeframe and resources required, including quick wins ('focused research is expected to generate immediate impacts'), best buys ('expected to yield outsized impacts'), and game changers ('expected to inform more transformative changes that will create immense positive impacts over time').

the potential and performance of water markets. A broader and multi-dimensional perspective on performance pays attention not only to distributional justice and who wins and loses, but also to procedural justice (decision-making processes) and long-term trade-offs. A systems perspective ties performance back to macro-level outcomes, such as economy-wide impacts, resource sustainability, and impacts on pre-existing inequalities.

In this context, our research vision is inspired by the potential for a global network of observatories to examine where and how water markets come into being, what problems they address and create, and how they work. Although observatories are most common in the environmental sciences, they are apt for situations like water markets that cut across social and hydrological systems and depend on field measurements of disconnected datasets covered by different disciplines. In some cases, existing data sources are not being effectively leveraged or harmonized (such as sample surveys conducted by governments, e.g. Demographic and Health Surveys or agricultural censuses). In other cases, new datasets are needed. A code book and metadata can guide data collection, but should draw lessons from existing experiences which note trade-offs between complexity and comparability, and ethical and practical factors which constrain coordinated approaches to data collection, sharing, and management [42].

Where to begin? Put simply, if we want to know a market, start with the transaction (see table 1). We know little about the amount of water traded, prices, and the types of buyers and sellers participating. Transactions also connect different subsystems—the source of water, the infrastructure used to deliver it, the drivers of scarcity, the focal participants, the rules and norms that govern trading, and the micro-, meso-, and macro-level impacts that connect behavioral changes and system-level outcomes. For decades, research on water markets has relied on grey literature transactions data, even in settings with the most formalized approaches to administrative approval and record keeping. An agreed common protocol for tracking transactions and trading activity is now within reach, and can form the bedrock for a global network of researchers and practitioners.

A distributed network of local partnerships, guided by common protocols and standards, can uncover the potential, limits, and pathways for water markets to contribute to more sustainable and inclusive water management.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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ORCID iDs

Dustin Garrick https://orcid.org/0000-0001-6504-6550
Soumya Balasubramanya https://orcid.org/0000-0001-8035-7306
Melissa Beresford https://orcid.org/0000-0002-5707-3943
Amber Wutich https://orcid.org/0000-0003-4164-1632
Gina G Gilson https://orcid.org/0000-0001-7162-1857
Isabel Jorgensen https://orcid.org/0000-0001-9348-5278
Nicholas Brozović https://orcid.org/0000-0002-2218-4934
Michael Cox https://orcid.org/0000-0002-3462-7798
Xiaoping Dai https://orcid.org/0000-0002-7300-7540
Sophie Erfurth https://orcid.org/0000-0002-0304-2797
Renata Rimšaitė https://orcid.org/0000-0001-6985-8601
Jesper Svensson https://orcid.org/0000-0003-2836-1994
Julia Talbot Jones https://orcid.org/0000-0002-8425-1792
Hita Unnikrishnan https://orcid.org/0000-0002-4298-4939
Charles Wight https://orcid.org/0000-0002-8704-9637
Sergio Villamayor-Tomas https://orcid.org/0000-0002-5170-1718

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