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Elevating the role of water resilience in food system dialogues

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ABSTRACT

Ensuring resilient food systems and sustainable healthy diets for all requires much higher water use, however, water resources are finite, geographically dispersed, volatile under climate change, and required for other vital functions including ecosystems and the services they provide. Good governance for resilient water resources is a necessary precursor to deciding on solutions, sourcing finance, and delivering infrastructure. Six attributes that together provide a foundation for good governance to reduce future water risks to food systems are proposed. These attributes dovetail in their dual focus on incorporating adaptive learning and new knowledge, and adopting the types of governance systems required for water resilient food systems. The attributes are also founded in the need to greater recognise the role natural, healthy ecosystems play in food systems. The attributes are listed below and are grounded in scientific evidence and the diverse collective experience and expertise of stakeholders working across the science-policy interface: Adopting interconnected systems thinking that embraces the complexity of how we produce, distribute, and add value to food including harnessing the experience and expertise of stakeholders s; adopting multi-level inclusive governance and supporting inclusive participation; enabling continual innovation, new knowledge and learning, and information dissemination; incorporating diversity and redundancy for resilience to shocks; ensuring system preparedness to shocks; and planning for the long term. This will require food and water systems to pro-actively work together toward a socially and environmentally just space that considers the water and food needs of people, the ecosystems that underpin our food systems, and broader energy and equity concerns.

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1. Introduction

1.1. Our food systems are in crisis

Despite recent setbacks from COVID-19 and the war in Ukraine, significant progress has been made globally in the production of food to meet growing demand. This is evidenced by *per-capita* food availability increasing since the middle of the last century despite a more than doubling of the global population [31] with a concomitant decline in the share of people undernourished at the global level. An important benefit of our ability to feed a growing population has been a significant decline in food prices (until recently), but this has come at the cost of detrimental environmental, economic, and social impacts [53]. An increasing number of countries are facing growing levels of acute food insecurity due to climate shocks, conflict, and other disruptions, reversing years of development gains [71]. This has been further exacerbated by the Covid-19 pandemic [93,47] and more recently by food price increases due to the war in Ukraine [30].

Notwithstanding the current impacts of the pandemic and the war in Ukraine, food and land-use systems are in crisis [20]. Food systems include the related resources, inputs, production, transport, processing and manufacturing industries, retailing, and consumption of food as well as its impacts on the environment, health, and society. At least four interlinked dimensions of systemic change are contributing to emerging food and nutrition insecurity, namely, (1) the climate crisis leading to an increasingly erratic water cycle and non-stationary conditions around the world, which is destabilizing agricultural and food systems as increased frequency and severity of extreme events, elevated temperatures, and floods and droughts take hold [42,43]; (2) an environmental crisis unfolding through exploitive resource-use expansion and poor environmental management, exacerbated by loss of biodiversity and ecosystem services that impart vulnerability to food and livelihood systems [71,8,42]; (3) a health crisis driven by lack of access to affordable and healthy food and poor nutrition choices [90]; and (4) a rural livelihoods crisis in many countries associated with gender inequality, paucity of livelihood opportunities, an aging agrarian population, and limited engagement of youth whose aspirations lay beyond the farm gate [96]. Moreover, while trade has been an enabler [64] of food and nutrition security—and plays a growing role in ensuring national food security of low-and middle-income countries, particularly in Africa - trade has, at times, worsened inequity and access to healthy nutritious food [9,20].

Whilst climate is a key driver of the challenges facing food systems, its Anthropocene origin and many other human-induced environmental challenges and impacts need to be acknowledged. We have built large conurbations in drought-prone regions without water retaining and water saving features, where populations continue to grow, placing greater stresses on limited water resources; we draw jurisdictional boundaries that cross catchments adding complexity to decision making; we grow water-intensive crops (e.g. sugarcane and rice) increasingly in areas where the water footprint of crops brings them into conflict with other water users; irrigate staple grain crops in a manner that destroys riverine and coastal fisheries that supply foods critical for nutrition, and we remain heavily reliant on rainfed agriculture. These are examples of the low priority given to water in our decision-making processes.

A core element of the UN Food Systems Summit was to raise awareness that achieving the Sustainable Development Goals (SDGs) demands reforms in our food systems. Whilst recommendations supporting reform and needed transformation of food systems were proposed [89], the criticality of water in these processes did not receive due recognition. In contrast, the recently published IPCC sixth assessment report highlights current and future challenges associated with future climates and implications with respect to water and food security. The report stresses the need to address systemic changes driving food and nutritional security and the need to build resilience into food systems to ensure the provision of healthy and affordable diets for all [43].

Disruption of the water system by climate change is creating risks across the food system. The impacts on food systems will be far reaching from the loss of land in the mega-delta food bowls of south, east and west Asia due to salt water intrusion [39]; changed flow regimes of major river systems from the Andes to the Himalayas [72,40]; shifts in precipitation patterns and snowpack/glacier melt impacting irrigated agriculture in Central Asia [5]; to abandonment of rainfed agriculture in regions of Africa due to rainfall unpredictability and desertification [80]. All of these shocks and stresses and, often solutions to them, are manifest in water [42,43].

The climate crisis is a *water resilience crisis*. The linkages between water and climate and complex and water and climate change are inextricably interlinked [46]. Water is the primary medium through which climate change manifests itself including in droughts, floods, water stress, and by affecting water quality [84]. Water and sanitation systems produce significant carbon contributing to around 10 % of global greenhouse gas emissions per annum and have shown to have limited resilience (GIZ, 2020 cited in [83]: 8). Water resilience is therefore critical to addressing climate change. To meet our aspirations for future food systems, there is a need to transform governance systems relating to food and water to properly value water resources to cope with variability in frequency, location and amplitude of water-related extreme events, as well as actively addressing justice and equity concerns. The question arises: What are the unique elements for governance of water resilient food systems?

Whilst it could be argued that the innate complexity embedded in water - spanning social, economic and environmental domains - makes identifying the constituents of water resilient food systems a tortuous and contestable task, we are of the opinion that it is essential.

The objective must be to prepare for a resilient future that embraces water scarcity, systemic changes in availability and competition. Water use in food systems has to be brought within the limits of sustainability, and food systems need to be ready for a productive future with unpredictable water. Further, change in food systems must respect the planetary boundaries for water resource use [78] and to reclaiming space of social and environmental justice in food and water systems. It is also argued that given the context-specific nature of water and that some river basins are already under stress, production will need to increase elsewhere.

Water is too often left out of the discourse around resilient and sustainable food systems and treated as an unlimited resource. There is little to no consideration of structural barriers towards equality in access to water and its availability (as well as quality) is taken as a given [79]; in the production and processing of food; in the consumption of food; and in equitably meeting demands from humans and nature [77]. The reality is water has the power to break “climate-brittle” food systems. Managing less and more variable water supplies will increasingly lead to access and supply failures through, for example, droughts and floods, or water contamination contributing to unsafe drinking water, malnutrition and associated disease. In short, water itself is a critical source of resilience (or, if mismanaged, vulnerability) across natural and social systems [21] and is reflected in the increasing adoption of new irrigation methods in such places as the mid-west of North America, important food producing areas in South America, and several Nile basin countries.

As mentioned above, to catalyse a new dialogue on water resilient food systems, there is a need to recognize the critical role that natural systems play in food systems, as well as hydro-social impacts to them, and ensure that their integrity and functionality is not compromised whilst serving humanity with accessible, affordable and nutritious food. We argue that good governance is the key to this and propose six attributes that together provide a foundation for good governance to reduce current and future water risks to food systems. The six attributes and their supporting references have been summarised in Table 1, below.

Much of the focus of this article emphasizes the role that participatory processes play in enabling the six governance attributes to evolve.

Table 1
Six Governance Attributes, their recommended actions, and supporting references.

Six Governance Attributes	Recommended Actions	Supporting Reference numbers
Treating the food system as a system	• Create new and innovative platforms and partnerships. • Develop participatory processes that share expertise among diverse groups. • Embrace uncertainty and complexity.	4, 11, 17, 36,38, 54, 55, 56, 58, 65, 70, 75
Adopting multi-level inclusive governance and participation	• Adopt polycentric governance with well-defined responsibilities and communication, fosters resilience across the inter-connected social-ecological systems that constitute water and food systems. • Foster systems that encapsulate elements of responsiveness, flexibility and equitable water sharing and distribution mechanisms.	14, 21, 26, 37, 50, 62, 63, 95
Enabling continual innovation, new knowledge, learning, and dissemination	• Incorporate the attributes of continual learning and associated feedback mechanisms that allow for improvements and course adjustment • Support innovations in incentive-based approaches that include payment for ecosystem services (PES) and conditional transfer approaches	12, 22, 23, 44, 45, 51, 59, 70, 74, 85, 86
Incorporating diversity and redundancy—living resilience	• Encourage and embrace diversity and social-ecological complexity in agricultural production techniques that incorporate broad and nimble adaptive capacity and build resilience	11, 17, 58, 73, 77, 82
Ensuring system preparedness	• Prioritize preparedness, a fundamental shift away from the current reactionary responses • Understand and predict how risks will cascade across water systems between regions and economies	3, 6, 11, 29, 52, 70
Plan for the long term	• Proactively plan for and adapt to system changes over both short and long timescales • Natural cycles and systems must be maintained to promote resilience	10, 58, 60, 68, 69, 71, 92

We take a wide view of participatory processes recognising that people and organizations can participate in financial markets, politics, rights-based approaches, and even in fiscal and planning in a myriad of ways, and these multifaceted types of participation are key to how we discuss governance in relation to water resilience [91,76].

These attributes are grounded in scientific evidence as well as our diverse collective experience and expertise working across the science-policy-practice interface. They should not be seen as exhaustive or a road map to success but rather the foundations of the urgently needed discussion on how to transform and build water resilient of food systems.

2. Treating the food system as a system – Adopting interconnected systems thinking that embraces the complexity of how we produce, distribute, and add value to food.

The water resilience of food systems is influenced and impacted by the numerous sectors that are dependent on water at different scales, creating feedback loops across the water cycle [75,4,66]. Water and food systems are constantly co-evolving, requiring continual assessment of decisions and adaptation for the sustainable management of food systems [11]. By acknowledging these feedbacks, connections and associated uncertainties, continual adjustments, synergies and trade-offs can be evaluated, and actions taken. To achieve interconnected systems thinking, new and innovative platforms and partnerships, which include farmers, need to be created and participatory processes used that share expertise among practitioners across the agricultural, environment, energy, and land-use domains along with other diverse groups that have an interest or stake in water and food systems. Evidence of the effectiveness of such approaches is found in innovation platforms that have emerged to address changes in small-scale irrigation in southern and east Africa, for example, and in participatory decision-making processes that have been tested in Vietnam [70,94].

The complexity of water resilience is eloquently encapsulated in the paradox of irrigation efficiency. Simple interventions through policy reform and investments in infrastructure or modernization of irrigation systems have rarely achieved the desired goal of reduced water consumption [33] when scaled up from the farm to basin. Results from theoretical studies of behavioural responses to water conservation technologies suggest that increased physical irrigation efficiency is unlikely to conserve water under generally prevailing conditions but typically leads to increased water consumption by farms and reduced return flows, which, under prevalent recoverable return flow regimes, will reduce water availability for other uses [19]. By embracing complexity that is inclusive over a range of social-ecological dimensions, scales and time, meaningful assessments can be undertaken of how to overcome the efficiency paradox [55]. Similarly, the adoption of nature-based solutions [58,36] and agroecological [38] approaches incorporate the complexity of natural systems in building water resilience into food systems [17].

The benefits of complexity thinking including a shift in the mental models and cognitive processes of all actors involved to embrace uncertainty, long-term thinking, feedback loops and understanding of food systems as social-ecological systems, with water a key leverage point for transforming them into resilient systems have been shown in crop systems and landscape management [65,56,54].

Embracing complexity provides the foundation for informed decision-making that goes beyond sectorial silos whilst recognising the benefits of deep expertise.

Building resilience for the vast challenges posed by global change, and coupled complex systems is not without challenges, however. Embracing complexity, identifying the boundaries of a system and its dynamics may be beyond the capacity, resources, or time limits of a given project, program, or decision. Navigating the trade-offs of what components of a system are more important than others is also complex. Modeling and improved data are making significant strides in helping with these challenges, but access to them is still limited and often costly.

3. Adopting multi-level inclusive governance and participation

Adopting polycentric governance with well-defined responsibilities and communication, fosters resilience across the interconnected social-ecological systems that constitute water and food systems. Polycentric governance involves multiple overlapping centres of decision-making which interact with an overarching set of rules [37]. Such an architecture for governance contributes to strengthening inclusion for women, youth and marginalized people, which is vital for resilience. It recognizes the differences between varied stresses on water and food systems and enables tailored policymaking to adapt to local risks [21]. Institutions within polycentric systems have the capacity to act semi-autonomously simultaneously, which enables adaptable, rapid, and inclusive responses to local threats to water security that could rapidly escalate across agricultural supply chains [14,27]. Where different polycentric governance institutions have overlapping interests across these nested systems, there is a need for effective platforms for negotiation that promote cooperation across the system as well as support robust conflict resolution mechanisms [14]. The potential for novel polycentric governance systems at scale has been identified for groundwater usage in sub-Saharan Africa [13].

Traditional participatory approaches provide concrete examples of polycentric approaches to water management at a local level. The Muang Fai [62] and Subak [95] irrigation systems of northern Thailand and Bali and the Qanats [63] of Iran provide examples of traditional communal management systems still in place that have undergone little change for generations. Cross-coalition coordination in collaborative environmental governance processes that seek to manage water in the Colorado River Basin is a recent example of a polycentric approaches [50] These systems encapsulate elements of responsiveness, flexibility and equitable water sharing and distribution mechanisms.

There are, however, lessons to be learnt in promoting polycentric governance structures, all part of a continual learning process that allows for improvements and course adjustment. The development of water user associations (WUAs) as a means of democratizing irrigation management is emblematic of a polycentric approach to governance and inclusiveness, with many different examples found in the developed world. Whilst this approach has been promoted in the process of irrigation reform in many developing and emerging economies, its impact has been mixed due to challenges of developing effective and sustainable institutions and can compete with other formal and customary rules and mechanisms [1].

Polycentric governance structures would facilitate the emergence of viable water resource institutions that are more transparent, accountable, efficient, responsive, sustainable, adequately resourced and geographically contextualized and would support improved governance where current arrangements are fragmented or weak. However, polycentric governance is also costly and subject to power dynamics [61]. Further, since water risks under climate change fall disproportionately on the most vulnerable, such an approach to water resilient food systems would encapsulate a strong lens on equity and local communities. Water resilient food systems should factor in the environmental and ethical costs associated with food systems.

4. Enabling continual innovation, new knowledge, learning, and dissemination

Water resilient food systems have embedded within them an ethos of continual innovation and learning along with access to knowledge and the skills and capacity to utilize knowledge in managing dynamically changing risks. They foster systems thinking, knowledge sharing and continual learning that is used to inform decision making. The development, promotion and use of climate and water information systems and the implementation of robust monitoring systems, supports and contributes to adaptive management across the entire food system.

To make use of information, water resilient food systems need to incorporate the attributes of continual learning and associated feedback mechanisms that allow for improvements and course adjustment. There is a range of information, knowledge and technological innovations and tools that could be used in promoting water resilience in food systems. For example, the concept of ‘follow the water’ through recent technological advances in real-time monitoring of flows using Earth observation tools [23] provides critical information required to build robust water accounting systems that can be used in decision-making processes [86]. Demystification of hydrogeology combined with community norms and institutional reforms to manage groundwater as social-ecological commons in Maharashtra, India, has been shown to be effective in addressing over exploitation of groundwater resources [51]. In addition, traditional indicators used in the past, such as water collection storage and infiltration with traditional rainwater harvesting, will need to be re-thought and expanded upon under climate change, since efficiency is not necessarily an indicator of resilience particularly from the perspective of justice of marginalised peoples [25].

Whilst the Information and Communications Technology (ICT) revolution and the emergence of Artificial Intelligence (AI) will play a significant role in supporting water resilient food systems with baseline data and evidence for the effectiveness of different management interventions, there is a need to ensure that indigenous solutions in water management are incorporated into the solutions mix. Rainwater harvesting systems, step wells, Persian wheels, etc. have been shown to be effective solutions for managing water resources. There is a need to revive and mainstream these approaches in the mix of options to be considered. Indigenous solutions often present a distinct diagnosis of water resilience, water management technologies practices, and water governance that sometimes clashes with global, national and local systems of governance [59,28]. Ensuring that indigenous knowledge, principles and values is given equal standing alongside other forms of knowledge will help address issues of environmental justice considerations when enabling continual innovation, new knowledge, learning, and dissemination [59].

Innovation is not confined to technology, but can include practices, policies,institutions and incentives. Advances in incentive-based systems and financial instruments have provided the enabling environment to facilitate behaviour change. Adoption of improved practices and approaches that contribute to water resilient food systems occurs where there is a clear benefit to the individual, these being primarily economic [70]. However, the adoption of practices and approaches that have a public and social good are often more difficult to achieve and less attractive due to perceived limited immediate benefits (e.g. financial) and in general require incentivization [16]. Innovations in incentive-based approaches that include payment for ecosystem services (PES) and conditional transfer approaches have been key mechanisms in support of improved resource management that can have positive impacts on the quantity and quality of water resources generated in landscapes. Examples include Conservation Reserve Program (CRP) [85] in the USA, the Grain-to-Green Program (GTGP) and the Grain-to-Bamboo Program (GTBP) in China [22], the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) in India [45], the combined actions under EU Common Agricultural Policy and 3rd cycle EC Water Frame work directives (2022–2027) and the procurement and public distribution of millets in Odisha [44]. There are currently over 550 PES programs globally, steadily increasing in number, with total annual expenditures that could soon reach over US$ 40 billion [74]. Contrasting this $540bn in global subsidies are given to farmers every year of which 90 % are viewed as “harmful” [89]. Despite their potential, formal water markets and other incentive-based approaches to water management have struggled to scale up beyond pilot initiatives due to political resistance, financing shortfalls and data deficits. While the limitations of water markets are important to recognise c.f. [34], recent advances in our understanding of incentives for sustainable water use can help to overcome persistent barriers that have hindered past efforts [26]. Emerging research on financial and investment instruments to support positive environmental outcomes [12] holds significant promise to support water resilience in food systems.

5. Incorporating diversity and redundancy—living resilience

Achieving resilient water systems that support food systems requires maintaining diversity and redundancy amongst component parts: from water landscapes to governance institutions [11,17]. Diversity and redundancy provide a range of options to respond and adapt to changing circumstances over both the short- and long-term [32]). Within most current food systems, prioritization has promoted leanness and optimisation over system flexibility. Large-scale production technologies and global trade of inputs have been successful at maximizing output by simplifying and centralizing agricultural techniques, but have created 'narrow and brittle' systems at the expense of risks associated with climate change and biodiversity loss [68]. These technologies have also emphasised the power asymmetries between farmers who can command such investments and those who cannot. By encouraging and embracing diversity and social-ecological complexity, agricultural production techniques can be made more flexible, incorporating 'broad and nimble adaptive capacity' (ibid) and building systemic resilience [73;58]. Evidence from the Mediterranean on nature-based solutions suggests that they have been effective in reducing water demand, improving soil fertility and have reduced erosion through the use of cover crops and agroforestry-based systems [82]. The adoption of regenerative agricultural approaches can help address land degradation and biodiversity loss whilst supporting diverse, productive and integrated farming systems. It provides the opportunity to conserve and value ecological diversity and connectivity, promote economic diversity and guard against maladaptive engineering [77]. The lack of progress in reversing the global decline in biodiversity is partly due to a mismatch between how living nature is conceived and valued by the conservation movement on the one hand, and by many different people, including marginalized communities, on the other requiring a pluralistic perspective on biodiversity [67].

A challenge of incorporating diversity and redundancy is that many governance and economic models linked to food systems and water are built around a focus on optimization and short-termism [18,88,24]. Optimization is often more cost-effective than redundancy and diversity in the short-term and communicating the long-term and short-term trade-offs to decision-makers is often a challenge (c.f. [49].

6. Ensuring system preparedness

Achieving water resilient food systems will require prioritizing preparedness, a fundamental shift away from the current reactionary responses [6]). In a changing world where future shocks and stresses cannot be perfectly predicted, resilience can be built by focusing more on preparedness and increasing the range of adaptive capacities [11], rather than trying to orchestrate precise response plans to specific predicted situations. In preparing for extreme events there are a range of tools and approaches that would assist in reducing their impact. These include long-term climate forecasting and early warning systems tools that would allow producers, water managers and other decision makers to make tactical decisions [3]; continual mapping of temporal and spatial trends of emerging water scarcity; establishing routine water accounting approaches at a national and sub-national level; and adapting agricultural water management to water scarcity and flooding, and increasing water demand driven by rising temperatures. Proactive approaches to water management have also been evidenced to be cheaper than responding to eventual shocks [6]. Understanding and predicting how risks will cascade across water systems between regions and economies and understanding potential water/agriculture tipping points and in some case opportunities that can assist in highlighting the myriad ways in which actors need to prepare [48].

In order to support a preparedness agenda there is a need for transparency in data availability, accountability in data management and collection, a change in data governance, and a shift in how investments for resilience are viewed. There are significant gaps in data collection across water systems worldwide; an increasingly important approach that can address this impasse is through citizen science and the citizen-state interface in data collection. Crop water budgeting successes in parts of India [29] and Africa [70] are evidence towards addressing this gap. Elsewhere, there is an important opportunity in making existing data sets more accessible where presently they are not for such reasons as concerns over miss-use of the information in disputes. Accessible data sets and open access platforms can also help promote cross-sectoral engagement and collaboration around complex systems problems including water resilience [52].

7. Plan for the long term

Throughout the world we find water infrastructure that was built thousands of years ago, from the aqueducts of ancient Rome or the Incans, to the irrigation channels of Mesopotamia or the Khmer Empire. Many investment decisions in water and food systems have long-term consequences. Infrastructure in particular can shape development for decades or centuries, a duration that often extends beyond infrastructure's lifetime because the economic system reorganizes itself around them [35]. Water resilient food systems must proactively plan for and adapt to system changes over both short and long timescales [71]. Climate change is making the water cycle increasingly erratic highlighting the lack of resilience in our current built infrastructure. It is likely to increase the frequency of extreme weather that will negatively impact agricultural production capacity [7]. One potential impact is multiple breadbasket failures if, for example, the jetstream stalls over key food producing regions causing prolonged droughts [92]. Earth has already been affected by two consecutive heatwaves across the entire northern hemisphere in 2018 and 2020. Water-resilient food systems should be built on a strong evidence base by potential long-term stresses. Hard and soft infrastructure and governance systems should then be designed to meet tests to resilience over a long time-horizon rather than focusing on present day stresses.

There is general agreement that many of the natural cycles and systems that must be maintained to promote resilience are not valued within financial models in accordance with their critical role in investment longevity. There are continuing debates over the monetization of nature in theory and also persistent practical challenges due to the need to effectively monitor, audit and compare impacts across biodiversity, water and human rights. As a transformational step, greater value should be attributed to the role these essential natural processes, including sustainable water management, play and every effort should be made in incorporating the true value of nature into financial and investment models.

Future-proofing water and food systems will require a step change in approach by policy and decision makers that shifts to preparedness for the long-term [58]. This requires a change in commitment by political leadership and governmental responsibility that needs to be driven by new structures of incentives that reward long-term value creation instead of short-term crises management and returns. Human rights-based approaches are being considered to identify and assess impacts of large-scale agriculture and water use, especially for countries actively importing high water footprint goods [60]. Previous studies of incentive take-up have found that successful initiatives are designed with specific target stakeholders in mind, rather than more generalized incentives [69]. Further, current incentives within food systems tend to reward short-term optimization for agricultural output [68]. There is a need to shift incentive systems to enhance the resilience of our water and food systems.

Longer-term planning and approaches also cut across key dimensions of justice and ethics linked to water resilience. For example, when natural systems and water resilience are protected over the long term, they can help to ensure the continuity of indigenous culture and they protect the myriad of core indigenous values that water connects with, and this, in turn, can help direct water governance [10].

Shifting away from short-term financially driven incentives and planning will require a transformational restructuring of what is seen as 'success' across the finance world as well as across governance institutions. There is the explicit requirement for agriculture to be profitable and provide short term returns, however, there is the need for incentives to transform to more sustainable and resilient systems. This will require political will that is not currently present.

8. Concluding remarks

Building consensus around what sustainable transition pathways for food systems constitute is difficult due to the complexity of these systems in the many different contexts, a lack of knowledge of the impacts of transitions across economies, and the diverse, and sometimes competing, incentives present across the wide diversity of stakeholders. Mindsets and mental maps need to be challenged to break down the silos separating communities of practice in water and food sectors. The TABLE initiative is an example of a dialogue platform that attempts to overcome barriers by providing a space for inclusive debates on the future of food [81].

Instilling resilience will require building adaptive capacity across stakeholders so that there is: a range of assets to draw upon; flexibility to change strategies; ability to organize and act collectively; learning to recognize change; and the agency to determine whether to change or not [15]), as well as safeguards and means of recourse to address increased vulnerability. Polycentric governance offers one model to deliver these ways of building adaptive capacity through organized collective capacity and coalition building [21]. Enhancing stakeholders' adaptive capacity requires collaboration between many different systems and policy departments which is complex and difficult to implement in practice; and can result in trade-offs [87]. There are also complex structures of regulatory and legal institutions that can create barriers to responding in flexible ways to changing circumstances [15].

Finding new ways of managing water and food systems will need to support the transformation of current patterns of production and consumption towards more resilient practices. This will require innovation ecosystems [41] whereby new approaches are funded, evaluated and the results shared across governance structures that support scaling. However, there are numerous barriers to scaling innovation across water and food systems. They include national and local regulatory restrictions, concerns of possible risks of adopting new technologies, and a lack of access to capital. All of these stifle innovative and experimental approaches to water management [2].

As uncertainty increases with climate change, our ability to identify the most likely and credible future water regime among a wide range of possibilities recedes. Due to non-stationarity, it is becoming harder to assign probabilities of future events with confidence limits and to then weigh alternative decisions. Instead, the best options for managing water are those that are robust because they show satisfactory performance across a wide range of possible futures [57]. If such robustness can then be complemented by flexibility, the ability to respond to unexpected future events, changes in climatic and hydrological patterns, and residual risk is retained [77].

Achieving the transformation to water resilient food systems will require difficult decisions, negotiation of trade-offs based on accurate, transparent and accepted data, significant investments across food and water systems and in the generation of new knowledge through research and its application. It will also require an enabling environment, building a compact between government, communities, producers and the private sector and the political will to stay the course. Further, women, youth and communities - including large and smallholder farmers - will need to be at the centre of decision-making, financial allocations for implementation and governance if transforming food systems are to be water resilient.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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