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Transitions in institutions for water allocation and rights: path dependence and performance

Guy Alaerts [a,*], Jonatan Godinez Madrigal [a], Leon M. Hermans [a,b] and Andrea B. Müller [c]

[a] IHE Delft Institute for Water Education, Delft, The Netherlands
[b] Delft University of Technology, Delft, The Netherlands
[c] University of Amsterdam, Amsterdam, The Netherlands
*Corresponding author. E-mail: g.alaerts@un-ihe.org

GA, 0000-0002-9537-2928; JG, 0000-0003-4685-4637; LMH, 0000-0002-5294-9045; ABM, 0009-0001-9594-405X

ABSTRACT

Many countries are already contending with relative water shortage where water demand structurally exceeds availability. Demographic and economic growth combined with deteriorating catchments and climate change will affect more countries and deepen this stress. To manage allocation effectively, institutional instruments are applied, comprising regulatory, economic and collective-action measures. In a longitudinal comparative analysis, based on a literature review and structured interviews, the development paths, instruments and performance attributes of emergent regulatory frames for institutional measures are studied in nine countries. In all countries, this development is taking decades to address deficiencies in effectiveness and, notably, to better incorporate environmental needs and achieve better equity. The regimes prove path-dependent and context-specific. To address the trade-offs between productivity and sustainability, and between security and adaptability, they show balancing dynamics over time: countries where private rights were strong have been attenuating and restricting these, and countries with traditionally strong administrative management now tend to create flexibility by introducing water markets. A lock-in effect of pathways related to private rights and markets appears to exist. Compared with the situation prior to the introduction of reforms, performance has improved, whereby each allocation regime features distinct advantages and disadvantages and some systemic challenges remain.

Key words: Allocation, Path dependence, Sustainability, Trade-offs, Water market, Water right

HIGHLIGHTS

- The negative impacts of poor water allocation are significant yet to be fully recognized.
- Building on earlier experience, several countries adapted their institutional allocation arrangements, which yields valuable lessons.
- Water allocation arrangements are increasingly required but are also expensive to the government and the users.
- All water allocation arrangements have strengths and imperfections; nations must find out what is most suitable for their circumstances.

INTRODUCTION

Water allocation, as the activity of matching water availability (*supply*) with water uses (*demand*), is becoming ever more important. Water allocation and rights arrangements determine who has access to how much water,

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of which quality, at which times, where, for which purposes and under which conditions (Uphoff 1986; OECD 2015). *Relative water shortage* (defined by demand structurally exceeding supply) and the resulting water insecurity – for households, industries, farms, the environment, etc. – are triggered by too little or too polluted water. Because demand and supply can fluctuate drastically on an hourly, weekly, seasonal and yearly basis, and demand often exceeds supply, allocation is also concerned with structuring and managing demand to adapt it to availability. Allocation is essential to provide water security to an existing or future user, critical in situations of long-term average or cyclic water shortage.

The unprecedented demographic and economic growth since the 1950s across the world, combined with degrading water catchments and climate change, has led to rapidly expanding water demand against constant or dwindling supply. The damage to society remains under-appreciated. While in 2010, about 16% of the world population was reckoned to experience water stress, by mid-century this will have increased to nearly 60% (Sadoff *et al.* 2015). Seventy-five percent of the world population is now living in 101 countries subject to 'continental drying' (Chandanpurkar *et al.* 2025). Increasing water shortages threaten many growing cities (He *et al.* 2021), industry and power generation (Gassert *et al.* 2017). Over-extraction of rivers upstream often contributes to over-extraction of aquifers downstream, causing widespread land subsidence (Herrera-García *et al.* 2021), peatland disappearance (Hooijer *et al.* 2012) and, along coasts, saline water intrusion and sinking of cities worldwide, but distinctly in Indonesia (World Bank 2021), China (Ao *et al.* 2024), Spain (Esteban *et al.* 2024) and Mexico (Zapata-Norberto *et al.* 2025). Relative water shortage, thus, creates growing financial risk for investors and households, and may exacerbate social inequities and conflict; it will grow into a main constraint for economic and social development both as direct damage and as opportunity cost (World Bank 2016; Dolan *et al.* 2021; Ligtvoet *et al.* 2023). Critically, in many countries, recent gains in water security and development now risk being reversed (ADB 2025). As users compete for increasingly scarce water, weaker parties tend to be overpowered, notably ecosystems, aquifers and vulnerable communities. Water shortage, stress and scarcity are relative concepts reflecting the ratio of demand over supply of water resources; relative water shortage arises in regions where demand structurally and over longer time horizons exceeds supply capabilities for shorter or longer periods.

Institutional responses

Since the 1960s, water became broadly recognized as a critical input to the economy, substantially raising the net demand and competition, while simultaneously the first climate change effects appeared. This spurred many countries to adopt institutional water allocation and rights instruments, notably since the 1980s, in the context of international policy debates and the introduction of integrated water resources management (IWRM) (ICWE 1992; Rosegrant & Binswanger 1994; Briscoe 1997; Easter *et al.* 1998; Björklund *et al.* 2000; Bruns & Meinzen-Dick 2000; Rouillard *et al.* 2022; Müller *et al.* 2026). Although ADB (2009), OECD (2015), the European Commission (Rouillard & Schmidt 2023) and the World Bank (Zhang *et al.* 2025) advocate 'better allocation', implementation and performance specifics of the institutional instruments remain scarce. Several countries have been particularly active in taking initiatives to develop, pilot and reform their water allocation policies and institutions, notably Spain, Chile, Australia, Mexico and South Africa, and later China and Jordan. Other countries such as the traditionally 'water-rich' Netherlands, the neighbouring Flanders Region (Belgium) and Indonesia currently also feel compelled to assess the scope for expanding allocation arrangements.

These reforms and pilots are providing useful lessons while not yielding a dominant approach or universal blueprint. Rather, configurations of allocation institutions and instruments appear context- and location-specific and must be adjusted by operational experience to achieve better functioning arrangements. What lessons are emerging for institutional change pathways towards more effective and sustainable water allocation regimes?

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Thus, we undertook a comparative analysis of the pathways of allocation policy development of representative countries, drawing from their economic, social, political and legal perspectives and traditions relevant for their water management.

Analytical frame and methodology

Analytical frame

The study explores institutional instruments and country specifics over a historical and geographic dimension, and aims to discover generic patterns rather than particular events. It focuses on water quantity, thus, less on flooding-related management or water quality. The study uses theoretical frames as guidance, though the complex, locally specific and contested nature of water allocation means that practice is highly context-sensitive and subject to the fluid nature of ownership, and, thus, must draw flexibly upon different disciplinary perspectives. As Meinzen-Dick (2000) points out, when irrigation water flows into and along a canal, it has ownership attributes of first the state, then the community, and finally a private individual. Hence, a pragmatic approach is taken, focusing on observation of the practical application of the allocation arrangement.

The analytical frame is based on key assumptions that were drawn from literature and prior field and policy experience of the authors. First, following Ostrom (2005) and Hermans & Cunningham (2018), we recognized that the allocation instruments combine with physical and socio-economic contextual factors to influence practices in arenas where water actors interact to produce allocation outcomes. These outcomes can be assessed for performance and trade-offs. In line with works by Young (2010) and work on dynamic systems in socio-hydrology (Di Baldassarre *et al.* 2018), we also expect that these outcomes shape a dynamic trajectory, whereby water allocation regimes change over time based on longer-term feedback loops. We classify institutional instruments in three categories (Dinar *et al.* 1997; Meinzen-Dick 2007; Alaerts *et al.* 2026a). *Permits and rights* emanate from the role of the State and its instruments of law, regulation and public administration. Important instruments are water permits (licenses, entitlements …) and government-controlled allocation structures and administrative mechanisms. Traditionally, water has been allocated through land-based property (e.g. riparian rights and rights over shallow and deep groundwater) and historical precedent (prior appropriation). New attention is given to customary law systems and justice principles, and land management and infrastructure that affect *de facto* allocation (Bosch *et al.* 2021). *Economic and market-based instruments* use economic principles of utility and economic value to allocate scarce water resources among competing users (e.g. Rosegrant & Binswanger 1994; Hellegers & Perry 2006; Garrick 2015; Shanmugaratnam *et al.* 2024) such as tariffs and taxes, water markets, subsidies, insurance and (virtuous and perverse) tax incentives (e.g. on power, land, agriculture etc.). *Collective-action approaches* are community- or water-user initiatives whereby the central role of water stimulates the emergence of groups, committees and platforms around water management, as well as cultural norms and practices related to water use and protection (Ostrom 1990; Warner 2006; De Groot & Hermans 2009). In many places, such traditional local practices have evolved into, or have been blended with, (semi-) formal water institutions operational at local scale and increasingly nested within regional or national allocation frames.[1]

These institutional instruments are often applied conjunctively for synergy or to compensate weaknesses, even though they may appear distinct and sometimes incongruent. Rather than offering alternative panaceas, the

[1] Examples are the Balinese *subak,* and Spain's old self-governing irrigation communities (*juntas*) such as the 10th-century Water Community of the Valencia Plain (*Tribunal des Aigües de la Veda de Valencia*). The *juntas* have operated for maximization of crop production contributing to over-exploitation of waters by the mid-20th century; the *subak* operating within the local Hindu traditions are reported to be more attentive to local sustainability (Lorenzen & Lorenzen 2005).

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three need to be used in combination (Dinar *et al.* 1997; Meinzen-Dick 2007). Normally, such instruments are to be applied purposefully within the water sector, but land policies, (power) subsidies, existing infrastructure, etc., indirectly influence allocation too.

It remains challenging to causally attribute allocation outcomes to specific institutional instruments, yet it is informative and feasible to identify the overall outcomes and explore correlations qualitatively. Following Scharpf (1997), institutional performance can be assessed by recognizing an institution as *functional* and *legitimate*. Functional performance relates to *effectiveness* (in achieving goals of economic and social development and minimization of negative unintended effects), *efficiency* (related to transaction costs) and longer-term *resilience* (ability to maintain functionality under changing conditions). Legitimate performance relates to dimensions of equity and fairness, such as procedural, distributional and recognitional justice (Davidson & Hellegers 2026).

The performance of an institutional arrangement is conditional upon the ability to navigate three fundamental trade-offs that do not imply reciprocal exclusivity but preference for one usually at the detriment of the other in practice: (1) between short-term economic productivity and long-term sustainability (w.r.t. ecosystems and aquifers), (2) between security of water access by incumbent users and adaptability (to changes in hydrology, new entrants, markets, etc.) and (3) between the natural tendency to monopolize or hoard water, and the desire to distribute access to water more widely and equitably.

Methodology

Nine countries were selected as case studies for in-depth reviews. First interview rounds in the Netherlands and Spain (2022–2023) allowed us to validate and improve the assumptions of the analytical frame as described above, and the interview protocol. Extensive structured interviews were held with a representative group of 104 key senior government, academic and stakeholder representatives, and field visits were conducted (2022–2025). The respondents were primarily selected from top policy, managerial and operational levels. Government and professional stakeholders typically included national government (policy, regulatory and operational divisions responsible for water, as applicable), provincial or district agencies, River Basin Authorities (RBAs), water user associations (WUAs), key national and regional agencies involved in water use (e.g. Ministry of Agriculture, districts), water supply utilities, and where relevant and feasible, farmer representatives and environmental groups. While they were selected to achieve a deep and balanced insight into current thinking in government and administration about the achievements and weaknesses in the allocation regimes, this does bring the risk of bias in respondent perception. However, in each case, also other stakeholders were selected and critical literature and reports were reviewed to identify and minimize bias. As respondents were aware of the sensitive nature of allocation, they requested anonymised responses; this text refers to 'Respondents' (listed in Alaerts *et al.* 2026b). Analysis of scientific literature, as well as official documents and grey literature, complemented and helped prepare the interviews. The succession in interviews allowed us to identify and resolve inconsistencies and provided a nuanced and adequately representative information base.

The country cases were chosen to reflect representative circumstances across the world, regarding relative water shortage, landscape and hydrology, economic development, governance and historical context. The selection was guided by the objective to extract lessons, not to suggest an evaluative judgement on these countries. Besides fit with study objectives, also considerations of familiarity and access played a role to ensure feasibility and quality of interpretation.

The scale of analysis is that of a jurisdiction where a coherent legal frame exists (country or state in a federal country). Because within countries often significant regional divergences exist, in most countries the analysis was limited to one or two sub-regions or river basins to illustrate prominent cases that are more advanced in

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the implementation of the allocation policies; the review also made an effort to identify other regions where implementation is encountering difficulties. The selected countries are Spain (Júcar basin), the Netherlands (western lowlands and eastern high sandy soils), Flanders (a Region in federal Belgium), Australia (Murray–Darling Basin), China (Yellow River and water trade pilots), Indonesia (Brantas Basin and South Sulawesi), Chile (central Regions), Mexico (Lerma-Chapala) and Jordan (Jordan Valley). Other countries deemed potentially relevant were excluded because already well documented or currently in a state of transition that may be less suitable to provide generic lessons.

To discern effects related to allocation instruments for the cases, a performance assessment was made that, however, in the absence of rigorous methodologies, can be only interpretative, tentative and qualitative. Because of the absence of a counterfactual, where feasible, a transversal comparative analysis was made with other countries at the same juncture while taking into account and interpreting differences in circumstances. Also, a longitudinal before/after (the reform) comparison was made, resting on a historical and timeline analysis. Special attention was given to former and current allocation regimes and the drivers and dynamics of transitions over the past about four decades.

Country cases

The eight most representative cases are described in condensed form here; extensive descriptions and additional cases are available in Alaerts *et al*. (2026b). Relevant for achieving comprehensive water allocation, the countries treat surface and groundwater differently: Spain, Australia, Mexico, Jordan and Flanders manage all water in an integrated fashion by one organization, but in the Netherlands groundwater and surface water are under different, albeit closely coordinating, authorities. Chile, Indonesia and China have fragmented groundwater management.

Spain

Spain's mountainous territory with fertile valleys combined with low annual precipitation[2] and sunny climate made it highly suited for irrigated agriculture, which was always productive (Sanchis-Ibor *et al.* 2022; Serrano *et al.* 2024; FAOSTAT 2025). Administratively, Spain comprises 17 semi-autonomous regions. It has a millennia-old legal tradition regarding water rights and irrigation institutions introduced during Roman and Umayyad reigns. The early 1866 and 1879 laws codified the private character of water abstractions. Following the 1975 transition from a technocratic dictatorship to democracy and growing recognition that over-extraction created conflict and degraded environment, the 1985 Water Act placed water resources into the public domain.

Like in most countries in the early 20th century, central government invested extensively in infrastructure to store and transport water to augment supply and boost economic productivity. By 1990, nearly all rivers and aquifers were heavily overused: rivers ran dry, ecosystems and fisheries disappeared, town water supplies suffered disruptions, and water conflicts afflicted many regions. After the 1985 reform, water management is based on 15 large river basins[3] and IWRM and sustainability principles. Surface and groundwater are managed by semi-autonomous RBAs. Water is allocated using a hybrid arrangement where users have to obtain a conditional water use *license* (*concesión*) that is entered into the Registry, and where both administrative decisions and local stakeholder platforms take prominent roles.

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[2] Spain's average precipitation amounts to 690 mm/year, but the central highlands (La Mancha) and the southeast (the Valencia, Alicante and Murcia regions) receive only 200–300 mm/year; this rainfall is highly variable between years.

[3] The nine large RBAs (*Confederaciones*) are Norte, Duero, Tajo, Guadiana, Guadalquivir, Sur, Segura, Júcar and Ebro. Six are under regional authority, i.e. Galicia, Baleares and the Southern Cuencas (Andalucía).

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A fundamental principle of the system is legal certainty for the licensee, although adding rigidity (Estrela Monreal *et al*. 2014). To increase flexibility (1) licenses are conditional, lapse (after 75 years but being reduced to 20–30 years) and are subject to administrative approval (like in China but different from Australia (see further)), (2) the RBA 'caps' the license to seasonally variable allocations depending on hydrological and demand forecasts and the priority schedule, in consultation with water users (quota) and (3) water market instruments were introduced (1999), i.e. *rights transfer contracts* where one user transfers water temporarily or permanently to another user, against compensation by the buyer. The RBA supervises (or initiates) transfers between users and between basins, and joins investments by users to save water.

A 10-level schedule helps prioritize allocation; currently, environmental needs constrain the variable quantity that can be allocated. However, across basins, little consistency exists in calculating environmental flows. Competition between agricultural, urban and environmental interests remains intense. A combination of subsidies, pricing and regulation spurs investment in water saving (agriculture, industry), recycling (industry, cities) and desalination. These instruments, together with trading, allow for reallocation of water volumes to new users and the environment, and help moderate the effects of severe drought episodes. Since 2001, *Rights Exchange Centers*, 'water banks', facilitate trades and set aside reserves for new users and sustainability. Even though total water volumes traded are only 0.5–5% of annual consumptive use, water trades help alleviate water shortages and re-allocate water to economically best usage or for environmental goals in critical locations (Estrela Monreal *et al*. 2014; Martín-Retortillo *et al*. 2020). Palomo-Hierro *et al*. (2015), however, argue that water trade does not yet achieve its potential due to institutional barriers.

Local irrigation communities manage and distribute water within their territory based on collaborative agreement. Because of joint decision-making and social peer control, discipline is high (Respondents 2023). Occasionally, agreements must be enforced. At the scale of the river basin, the RBAs are large technical administrations that rely on formalized consultation among water users. Many key decisions are taken by commissions with strong user representation. Underlying infrastructure is expensive; each plot in e.g. the irrigation system of the *Royal Júcar Irrigation District* has a pressurized pipe outlet with a valve and meter that are operated remotely: the central operator opens the valve after a farmer's request, depending on the farmer's remaining water budget and water availability.

Starting from the pre-1985 situation when essentially all water was directed at productive purposes, and river systems were structurally over-exploited, the implementation of the water reforms has been taking several decades, and the tension between productivity and sustainability is still to be definitively resolved. However, despite substantial water restrictions, industrial and agricultural production values have grown or have not declined from the high levels that were achieved in the 1950–1980 period of intensifying water use (Martín-Retortillo *et al*. 2020; Respondents 2023; INE 2025), while in many locations, environmental values and aquifers were being restored or better protected (INE 2018; Respondents 2023). Whereas until the 1980s, many town water supplies were unreliable during summer, this is no longer the case (Respondents 2023). Still, compliance with policy differs per region: while reasonable in the eastern (e.g. the Júcar basin) and northern basins, it remains weak in the southern basins. In the Júcar basin, irrigation water use has been curtailed drastically to re-allocate it to new entrants and to environmental uses: e.g. the allocation to the large irrigator *Royal Júcar Irrigation District* dropped from 700 Mm^3 annually in 1985 to 220 Mm^3 in 2020, releasing water for environmental purposes and restoring aquifers (Respondents 2023). Also, combining trading and subsidies, some Júcar water is now directed to the more southern area of Vinalopó-Alicante, which has reduced the over-exploitation of aquifers there (Sevilla & Torregrosa 2011). On the other hand, an initiative to direct Júcar water through trade to the neighbouring Segura basin was rejected: first, the over-allocation in the 'own' Júcar basin had to be addressed

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(Sanz Cavero *et al*. 2023). Despite this progress, further measures are needed to enhance sustainability (Sanchis-Ibor *et al*. 2022; CHS 2023; Respondents 2023).

In the other regions, water saving is intense, but overall use remains locally too high, damaging the emblematic Cota Doñana (Andalucía) and Tablas de Daimiel (La Mancha) wetlands and drawing down aquifers (Segura); these regions also suffer from among the highest rates of land subsidence in Europe (Esteban *et al*. 2024). News sites (i.e. Facebook, inspain.es, www.surinenglish) report that the National Guard prosecutes each year hundreds of landowners using illegal wells, notably in the southern regions.

Although much of the allocation is of an administrative nature according to agreed protocol, regional politics interfere. Castilla-La Mancha Region, upstream of the Júcar, keeps allowing groundwater extraction despite court orders, affecting the Júcar aquifer (Esteban *et al.* 2016; Respondents 2023). In the north, the Aragón Region refuses to share Ebro River water with downstream Catalunya to serve Barcelona (Marti 2000). Legal disputes over intra- and inter-basin transfers and calls for greater regional autonomy in water management reflect a governance landscape defined by cooperation as much as by competition (Martínez-Dalmau *et al.* 2023). The Ministry of Agriculture, Fisheries and Food keeps promoting irrigation expansion. Since its 1980s reform, Spain chose to build on both its strong legal traditions and legacy of collective action, creating capable RBAs and capped concessions with a supplementary role for water markets. Progress on sustainability is checkered and, like elsewhere, will remain a continuing challenge as competition will persist. In the longer run, however, deeper restructuring will become inevitable with 61% of the (semi-)arid zones at desertification risk, depleting aquifers and climate change (Greenpeace 2023; Martínez-Valderrama *et al*. 2025).

Australia

Australia is a vast continent with most of its comparatively small population concentrated along the eastern and southern coastline. Although it enjoys a high average water endowment, rainfall and evapotranspiration vary by region and season and are subject to 5- to 10-year weather cycles. The Millennium Drought (2000–2009) was devastating. Long dry periods are alternated with tropical cyclones that flood vast areas. To mitigate this, much infrastructure for water storage and canalization was constructed in the 20th century. Australia is a federal country. Water is under state authority, but the (federal) Commonwealth sets the regulatory principles and assumes specific management roles. Its Murray–Darling Basin (MDB) crosses five states and produces about half of the country's agricultural output; it covers about one-third of the nation, is as large as Spain and France combined, with a population of only 2 million, and serves about 55% of all water use in the country (Figure 1). The Commonwealth notably finances the environmental water reserves and keeps oversight through its Murray–Darling Basin Authority (MDBA).

Prior to 1991, state Irrigation Departments were responsible for water, but the sector was weakly regulated. Legislation was fragmented; it encouraged supply-driven infrastructural investment and witnessed unfettered competition between users, sectors and states, overuse of rivers and groundwater, bankruptcy of many farmers, environmental deterioration and deprivation of First Nations. In the downstream state of Victoria, parties invested in canalized irrigation and in groundwater wells starting in the 1920s. This spurred a strong sense of private, land-related entitlement to water. Responding to general malaise and economic stagnation in the 1980s, reform began through the 1991 Council of Australian Governments Water Reform Framework, initiating transition to a hybrid water management system in which water markets and strong administrative regulation operate conjunctively. Milestones include the National Water Initiative (2004), the Commonwealth Water Act (2007) and the Murray–Darling Basin Plan (2012). The Initiative is currently being renewed (APC 2024).

To reverse over-exploitation, the annual allowable withdrawal under private water titles was progressively restricted ('attenuated') after 1994, transferring greater authority to state water and environmental

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Fig. 1 | The Murray–Darling Basin and its major sub-basins, sprawling the States of Queensland (QLD), New South Wales (NSW), Victoria (VIC) and South Australia (SA) (©Murray–Darling Basin Authority).

administrations; during dry periods, the allowed withdrawal may go as low as 10% of the legal entitlement. The Commonwealth also launched in 2007 a multi-decadal A$30 billion (US$19.8 billion) programme to buy back water entitlements and restore flows for First Nations and environmental purposes. These rights are in

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the hands of independent Commonwealth and State *Environment Water Holders* that also engage in trading (MDBA 2025). Complementary initiatives, e.g. the Sustainable Rural Water Use and Infrastructure Program (2016), recover water savings through infrastructure upgrades and improved efficiency.

Water entitlements and land rights were unbundled: users hold water as a distinct tradable and mortgageable asset. Each year, states define sustainable diversion limits – after setting aside water for ecological functions – and determine annual allocation volumes based on hydrological forecasts. After slow adoption, water trading expanded gradually starting late in the Millennium Drought to comparatively large volumes and transaction values now, suggesting growing confidence of water users in the transparency, usefulness and fairness of the system. Still, further regulations to ensure price transparency and avoidance of market manipulation are being initiated (ACCC 2023). States must submit Water Resources Plans per sub-basin, accounting for all entitlements, to be accredited by the Commonwealth. Sub-regional Water Corporations process water calls and trade applications and deliver water within 10–20 days. Water management, trade and pricing are assessed by several independent regulatory agencies.[4] The water tariffs remain cheap compared to, e.g. Spain and the Middle East, yet trade prices are substantial (Alaerts *et al.* 2026a). Governments finance much infrastructure also for irrigation. A significant portion of the tariff is fixed, effectively charging for unused water. Collective action among users is prominent: Irrigation Corporations and similar institutions are run or supervised by the water users. In most sub-basins, Basin Officials Committees and Basin Community Committees steer local policies and matters.

Overall, most water users, states, regulators and academics confirm that water trading has been delivering an economic and social impact while helping ensure better sustainability, adaptability to climate and market shifts, and securing public and equity interests (ACCC 2023; Respondents 2024). Importantly, enforcement has been reasonably effective over the past decade in reducing infractions (Respondents 2024). Nonetheless, some Inspectorates and several scholars are critical (Grafton *et al.* 2012; Wheeler 2022; Waldman *et al.* 2023), pointing out weaknesses, some of which are currently being addressed. In the hilly southern MDB, 80–98% of all surface and groundwater abstraction points are metered, mostly telemetrically with certified meters, but in the northern MDB (where flat expansive land only allows drainage harvesting in large ponds) and other basins, only around half of the abstraction points have certified meters and only half of transactions are posted publicly (ACCC 2023). Some Water Resource Plans in New South Wales and Queensland are still in the process of accreditation. While in the southern part (Victoria), early enforcement efforts have significantly reduced infractions, compliance in the northern part remains more challenging (Wheeler & Xu 2021; Respondents 2023, 2024).

Comprehensive allocation, metering, hydraulic connectivity and transparency are thus found to be preconditions for the operation of water markets. While the administration of this trade arrangement comes with significant transaction costs and vulnerabilities, it appears decisively more effective and sustainable than the before-1991 situation (Respondents 2023, 2024). Importantly, the arrangement also allows market-conform compensation to users who decide to discontinue their water use. This transition proved time-consuming and its implementation is still being rolled out in more remote areas. Because of this long implementation time, the transition is sensitive to changing political majorities in the Commonwealth and state legislatures; e.g. the

[4] The federal MDBA must approve all River Basin Plans submitted by the states, the Australian Competition and Consumer Commission reviews all charges and subsidies as well as (risk of) monopolization and speculation, the Australian Productivity Commission assesses whether water is used effectively, the Australian Tax Authority assesses (risk by) international investment and the Australian Meteorological Authority and the Department of Agriculture, Water and the Environment review the overall hydrological, environmental, economic and social impact.

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buy-back programme was suspended between 2014 and 2022 when a conservative majority took power, but resumed in 2022.

China

China features hydrological conditions that are highly diverse; the west and north tend to be dry to arid and mountainous, while the eastern regions comprise expansive low-lying fertile plains. Industry is highly diversified and developing fast, while agriculture remains key for food security; 60–70 million ha is irrigated (van Dijk & Geurtsen 2023). Overall, agriculture accounts for about 60%, industry 17% and cities 10% of water abstraction; the remainder is nominally assigned to ecosystems (MWR 2021). The country is crossed from west to east by the large Yellow, Huai, Pearl and Yangtze Rivers. Water resources are distributed unevenly (Cheng *et al*. 2009), contributing to stark regional and seasonal water scarcity. Severe flooding alternates with droughts; extensive hydraulic infrastructure has helped mitigate this imbalance since the Han dynasty 2000 years ago (Ball 2017). Heavy investment in irrigation expansion, started in the 1950s, was often driven more by political ambitions than technical expertise, sometimes aggravating water shortages and causing, e.g. the Yellow River to run dry before reaching its estuary. China has a unitary political and administrative structure, with the Communist Party dominating civil government. The State owns all water, and individuals cannot exert rights. The Ministry of Water Resources (MWR) sets policy and manages the main infrastructure, i.a. through its River Conservancy Commissions, one per main river (though called Commissions, they are central government administrations) (Respondents 2023). Groundwater management is fragmented.

The adoption of IWRM in the late 1990s (2002 Water Law) remedied many deficiencies and for example ensured allocation of adequate volumes in the Yellow River to flush sediment and restore the estuary (Jia 2024). The 'chief river system' directs freshwater flows to perform other essential functions at macro scale, especially in the eastern plains: facilitating navigation, mining and industry, flushing out sediment, preventing flooding, repelling salt intrusion and restoring wetlands. The River Conservancy Commissions set a river basin plan, and decide on annual (and when necessary, monthly and 10-day) allocations for, and instructions to the provinces and large users. The State Council has capped the aggregate consumptive water use per main river, but it is unclear how well this is enforced (Yellow River China n.d.). The Commission issues water use permits to these aggregate, region-wide users. When a new entrant seeks a permit, existing water must be 'freed up': an existing user must forego his right, or water is 'created' through water-saving investments or recycling.

At the province, prefecture and county/municipality levels, Water Resources Bureaus are in charge of local allocation; they issue use permits to municipalities, industries, power generators, irrigation districts (WUAs and collectives), etc. Within these networks, water is further allocated and distributed. Generally, water fees tend to be too low to incentivize water saving, though end-users often pay significant tariffs for their water. On the other hand, the overall caps on rivers combined with regulatory pressures lead to more water recycling. To protect declared environmental sites, minimum flows are defined.

Although market-based trading is anathema to communist ideology, extensive pilots in seven provinces have been initiated after the Interim Measures for Water Allocation (2008)[5] to help address severe water shortages and competition in several regions and to respond more flexibly to local fluctuations in water availability and

[5] The Dalat power plant expansion (Ordos, Inner Mongolia) was the first pilot project in the Yellow River Basin (2003). It invested ¥120 million to stem leaking in 45 km of irrigation channels upstream. It thus 'purchased' more than 20 Mm^3 of water quota per year. Given the regional use caps of the Yellow River allocation plans, some provinces/counties 'sell' water saved in the agricultural sector to industrial users to spur local economic development. Such trades are tightly orchestrated by local government. About 300 Mm^3 was thus transferred by 2018 in 40 projects, nearly all from agriculture to industry and mining (Jia 2024).

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market prices. These measures offer more security; however, rights may be adjusted in non-transparent ways (Mu & Chen 2022). Gansu and Ningxia provinces, both arid, are at the forefront (IWRA 2023). To enhance transaction volumes and transparency – a precondition for functional markets – the China Water Market Exchange was established in 2016 (CWE 2025) (Figure 2). However, direct agriculture-to-industry transfers remain rare; rather, agricultural rights are acquired by governments for unified reallocation, reflecting a 'quasi-market' approach. Trading enhanced agricultural water conservation and transfer to more efficient sectors, yet many transactions, notably local ones, go unrecorded (Respondents 2023). The expansive network of waterways also allows water trade over the over-1,000 km-long South-to-North Water Transfer, with the water-short Northern China Plain (Beijing, Tianjin) 'buying' water from irrigation regions in the wetter south.[6] Concerns exist regarding the low prices offered, and the requirement that transactions must be approved administratively – a source of interference and causing prohibitive delays ('hysteresis') (Respondents 2023, 2024). Overall, this market-based allocation has enhanced flexibility, security and economic productivity, but environmental interests have not benefited (Svensson *et al.* 2021; Di *et al.* 2020).

Collective action takes place primarily through the Party as it claims to represent the interests of the whole citizenry. Collective action at the local scale used to be common, especially with respect to local management of irrigation canals, drainage and flood protection, but was forbidden under communism (Ball 2017; Respondents 2023). Since the 2000s, farmers have again been encouraged to organize in structured WUAs to enhance productivity and improve water management; their performance remains checkered, however, with unsatisfactory performance attributed to the absence of supportive conditions and the politicization of WUA leadership in China's centralized political system (e.g. Wang & Wu 2018; Respondents 2023). Rosa *et al.* (2019) concluded that 66% of China's irrigation water consumption keeps exceeding local renewable water availability. Chinese coastal cities are suffering from widespread land subsidence, mostly attributable to over-extraction of local groundwater, triggered by overuse of rivers upstream (Ao *et al.* 2024). CWE (2025) reports even water purchases by water utilities in the wet Shanghai region. Environmental flows are set aside, and though substantial progress was achieved after the 1980s, the environment remains severely stressed (MEE 2024).

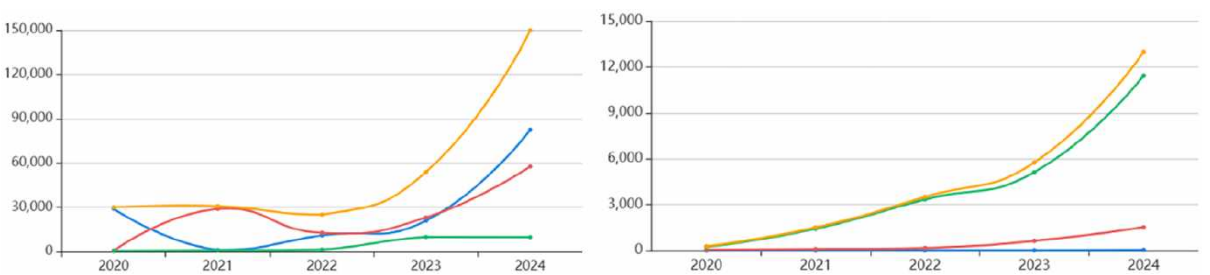

Fig. 2 | Water trade on China's Water Market Exchange. Left: volumes traded (in 10,000 m^3). Right: number of transactions. Yellow: Total; Red: inter-regional trade; Blue: individual withdrawal trade; Green: irrigation rights trade. Inter-regional trades are few but concern large quantities, whereas irrigation-related trades concern small volumes but are increasingly numerous (CWE 2025).

[6] For example, in 2015, a 20-year contract transferred 22 million m^3/year from Pingdingshan city (Huaihe Basin) to Xinmi city (Yellow River Basin) at the relatively elevated price of ¥0.87/m^3 (about 12US¢/m^3) (Jia 2024).

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China has a millennium-old tradition of public administration and engineering in water management. Under Deng Xiaoping, China's policy prioritized economic development and political stability while introducing market-based instruments to enhance productivity but slowly recognizing sustainability limits; this has created much wealth at a rapid pace while halting further environmental degradation. The country's political regime, however, is now showing more interest in water infrastructure expansion again at the expense of demand management, and a prevailing suspicion towards market-based and collective-action instruments.

Mexico

Mexico's ecological diversity mirrors the uneven distribution of water and economic activity. The south, with high water availability, remains largely agricultural, while the industrialized and urbanized centre and north, housing 77% of the population and generating 80% of GDP, face water constraints although they are endowed with 1,650 m^3/cap.year (Conagua-Semarnat 2016). Through much of the 20th century, water policy was shaped by the 'hydraulic mission': every drop should serve productive use before reaching the sea (Wester *et al.* 2009). This ideology underpinned widespread dam and well construction up to the 1980s, when irrigation and utilities were still centrally managed by a large federal administration (McCulligh & Tetreault 2017; Godinez Madrigal *et al.* 2018; Respondents 2023). As a result, already after 1947, some aquifers were being over-exploited (Reis 2014).

By the late 1980s, public expenditure on water turned so highthe system could no longer be sustained, while productivity remained stagnant. To address this, neoliberal reforms shifted governance towards market-based approaches aiming explicitly at greater water productivity and fiscal efficiency (Castro 2007; Wilder 2010; Respondents 2022) but were mute on inequalities, urban–rural water conflicts and environmental impacts. The 1992 National Water Law, also inspired by IWRM, transformed governance (Molle 2008): water is national property but can be concessioned for use, without transferring ownership. Irrigation management was transferred to WUAs (Rap 2006). Basin councils (*Consejos de Cuenca*) were established to foster participatory planning across sectors (Caire-Martinez 2004). The National Water Commission (CONAGUA) calculates water availability, issues concessions, imposes restrictions in over-exploited aquifers and develops infrastructure and the National Water Plan. Concessions are granted for 10–30 years and are fixed, not adjusted to fluctuating availability. Initially, water users needed to regularize their current water use but could obtain a concession larger than their actual use, leading to abuse. For groundwater, concessions were initially only needed for over-exploited aquifers but in the 2010s, CONAGUA required users to regularize all uses. All concessions, now over 500,000, are recorded in the Public Registry of Water Rights (REPDA) and are subject to use-based charges and renewal fees. CONAGUA established norms to estimate water availability in main rivers; however, the gauging network is limited to large rivers, creating a considerable mismatch between official estimates and field reality. In 2012, the Constitution was amended to include the human right to water, but legislation is lacking.

Informal temporary transfers within irrigated areas have been common (Respondents 2023). While concessions are formally not transferable for 'profit', transfers introduced in the late 1990s allow for administrative reallocation in aquifers where concessions had been frozen (Reis 2014). Transfers, e.g. between farmers, need only approval of the council of irrigation districts; inter-sectoral transfers require CONAGUA approval. Theoretically, REPDA records these transfers; in practice, most intra-sectoral transfers go unrecorded. Water banks appear to function only as a service window (Agular Amilpa 2013). Groundwater is the most transferred (≈2.5 billion m^3 per year) compared to surface water (≈865 million m^3, excluding transfers for energy generation) (Agular Amilpa 2013). Most transfers (≈73%) occur from agriculture to industry. Water prices for extraction vary by sector and volume but do not reflect limited availability and often exclude agriculture,

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where farmers typically do not pay volumetric fees (Wilder & Romero Lankao 2006). The national energy utility applies a low agricultural tariff that subsidizes farmers to pump groundwater (Respondents 2024).

Participatory water governance is formally promoted through Basin Councils, WUAs, Aquifer Committees and Technical Groundwater Committees (COTAS). The nationwide Irrigation Management Transfer in the 1990s aimed to democratize water governance (Wester *et al.* 2009). WUAs schedule deliveries, approve water transfers and resolve conflicts. User participation is, however, constrained by vague legal mandates, limited financial resources and weak empowerment. In several regions such as Jalisco and Puebla, water defense collectives have emerged to protest over-extraction and inequitable water access. As agricultural and smaller uses remain largely unmetered and are rarely reported, and enforcement capacity is minimal, actual withdrawals keep diverging from formal concessions. Transfers are bureaucratic and poorly monitored, and often illegally ceded to industrial users brokered by *coyotes* (Reis 2014). Though subsidies improved efficiency, they often boosted water use. Incentives often do not align with sustainability, but reward overuse and contribute to inequities between well-capitalized users and smallholders. Despite supporting strong agricultural and economic growth and protecting some ecosystems and aquifers, many water bodies end up overused (Respondents 2024). Overall, access to affordable water remains uneven, livelihoods dependent on irrigation remain insecure, and ecosystems and aquifers are under growing pressure (Herrera 2017; Hoogesteger & Wester 2017; Respondents 2024).

Chile

Water resources and population are distributed very unevenly. In the central regions, home to half of the population, it is about 3,100 m^3/cap.year (DGA 2016). Chile contains 101 river catchments and 137 aquifers forming 375 'hydrogeological sectors of common use' (SHACs). Rivers are typically short and steep, in parallel valleys. Groundwater resources are facing pressure: 47% of SHACs now face restrictions on new water extractions (DGA 2016). Water availability has been strained by a population doubling since the 1960s as well as La Niña cycles, with the dry spell 2010–2022 the longest on record (Garreaud *et al.* 2020).

Whereas water was managed until the 1960s by an expansive technical administration (Bauer 1997), Chile's 1980 Constitution was inspired by a neoliberal agenda, though the Water Code (1981) states that water resources are national goods of public use. The country's water governance is decentralized, with regional governments responsible for management of water resources. National policy traditionally prioritized irrigation infrastructure and conservation agriculture. Agriculture accounts for about 78% of total withdrawals, though government plans aim to reduce this to 60% by 2030 (DGA 2016; Respondents 2024).

The General Water Directorate (DGA) grants water use rights that are fixed; they are tradeable and mortgageable economic goods decoupled from land ownership (Bauer 1997). Rights used to be registered at local Real Estate Offices only, though they are now being recorded centrally; regulation and monitoring are still fragmented and very light compared to e.g. Spain and Australia (Respondents 2024, 2025). This institutional design enhanced allocative efficiency and investment but also entrenched inequalities in water access and environmental degradation. Weak measures for easy and transparent transfers and trading create market failures due to e.g. information asymmetries and lack of trust, resulting in a sub-optimal system (Budds 2009; Prieto *et al.* 2022; Pryke & Allen 2022; Respondents 2024). Bauer (2004) found that even in arid northern basins, less than 5% of rights were traded. Collective-action platforms play pivotal roles. Day-to-day allocation on rivers and canals is handled by autonomous WUAs such as the *Juntas de Vigilancia*; they distribute flows proportionally to right holders.

Under public pressure, the Water Code was amended in 2022 to strengthen environmental protection and curtail the perpetuity of private concessions. It also strengthens DGA oversight and monitoring; restricts new rights

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in depleted areas; lends environmental authorities and courts powers to protect in-stream needs; and – since 2005 – imposes a fee on unused rights (Budds 2020; Respondents 2024; Celume *et al.* 2026).

The water market has provided much-needed flexibility, particularly during droughts. For example, water can be transferred, against compensation, from annual crops to higher-value perennial export crops. Still, key weaknesses remain: the small regulatory and enforcement capacity, the vulnerability of aquifers and ecosystems and the absence of centralized market information and price-revealing mechanisms (Respondents 2024, 2025). New private initiatives such as *Agua Circular* (https://www.aguacircular.cl) provide open on-the-spot transactions. In contrast, the spot market is more effective, as it is managed by the WUAs that publish the trading rate, who are offering and who are demanding water. Partnerships are being fostered between civil society organizations, the private sector and government agencies (Respondents 2024). Such collaborations have supported wetland restoration, conservation projects and the strengthening of water governance capacities. While markets enabled flexible reallocation (e.g. around Santiago), they also externalized social and ecological costs, and left Indigenous and smallholder users relatively exposed, even after the 2022 reforms (Respondents 2024, 2025; Rivera & Donoso 2025).

Indonesia

This lower-middle-income country is a vast, sprawling tropical archipelago that has been enjoying steady economic growth for the past decades. Sixty percent of the population (i.e. 150 million) lives on the main island of Java, which is experiencing major relative water shortage and groundwater over-exploitation since the 1980s. Irrigation of rice and sugarcane remains the largest water user (World Bank 2021; BAPPENAS 2023). Urbanization has expanded relentlessly, currently encompassing 70% of the island's population (Pravitasari *et al.* 2024), with concomitant growing water demand. Both officially and in practice, the environment still has lower priority than economic growth. Furthermore, deforestation, intensive drainage and climate change have driven water demand beyond sustainable limits (Respondents 2023, 2024). A major yet unrecognized consequence of poor allocation upstream in rivers has been the over-pumping of coastal aquifers, causing widespread land subsidence in Jakarta, Semarang and Cirebon – aggravating recurrent flooding from rivers and the sea (World Bank 2021).

Policies before 1999 prioritized infrastructure development (Kaspersma *et al.* 2012), but the 2001 National Water Reform decentralized part of water management and assigned users greater responsibility in management. New institutions were established to allocate scarce water among competitive uses: (1) River Basin Administrations (RBAs, *Balais*) under the Ministry of Public Works, (2) collaborative irrigator institutions that manage canal systems and help distribute the water within their area (WUAs and Irrigation Commissions) and (3) Water Resources Coordination Teams (*TKPSDA*) to convene water users and main stakeholders to represent the 'demand side' and help negotiate allocation of water (Alaerts 2020). RBAs prepare annual technical allocation plans but lack protocols to collaborate with the cities, irrigators, industry, environment, etc., to deal with changing conditions and varying demand; they lack staff and measuring equipment to monitor water withdrawals (Respondents 2023, 2024).

The RBA issues water use permits against a fee to industries and water supply utilities, valid for 2 years only. Permit holders must self-report their withdrawals, though they too mostly lack reliable equipment. The Water Law sets the priority schedule for allocation: household water gets top priority, State-owned industries enjoy priority over most other uses and small-scale farmers enjoy a basic free allocation. This cannot be implemented for lack of administrative capacity. Permits for groundwater withdrawal, issued by provincial Mining Administrations, are disconnected from water management. Water users pay a modest withdrawal fee to the river basin operator (*Perum Jasa Tirta*). However, obtaining a permit is laborious and expensive, so many users forego the application. In practice, when reservoirs run low at the end of the dry season, paying permit holders

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tend to get priority over other users; small-scale farmers have few means to enforce their rights. Other ministries and local governments often thwart the allocation plans, e.g. by donating pumps to farmers when river water levels drop (Kurnia *et al.* 2000; Respondents 2023, 2024).

Indonesia's long tradition of community irrigation management – exemplified by Bali's *Subak* system – helped inspire the 2001 reform, which established thousands of WUAs. Many function effectively as dynamic, locally rooted organizations; others struggle with limited capacity or elite capture (Alaerts 2020; Respondents 2023). WUAs have boosted irrigation reliability and, thus, rice yields but prioritize productivity over sustainability. Water is managed by the State as a public resource; permits are non-tradable. Yet, informal, negotiated water-sharing arrangements are widespread, allowing farmers or neighbouring WUAs to exchange turns or compensate each other in kind or money. Such reciprocity helps adapt to seasonal variation and local conditions. Coordination among WUAs has improved water distribution and security (ADB 2016, 2017): in Central Java, district irrigation departments now routinely consult WUAs on allocation (Suhardiman & Giordano 2014) and upstream and downstream WUAs along the Sampean and Citanduy Rivers have agreed to share water seasonally based on soil suitability, crop type and rainfall (Alaerts 2020; Respondents 2023, 2024).

Despite progress, sustainability remains weak. In around 80% of Java's water bodies, biodiversity continues to decline, and coastal aquifers are severely depleted (ADB 2016; World Bank 2021; Respondents 2023, 2024). While the reform improved allocation efficiency, institutional and financial capacity in government agencies lags behind local collective-action initiatives. Overall, Indonesia's water allocation reflects a pragmatic blend of state regulation and local collective action under constraints of weak governance capacity. Although imperfect, the gradual, learning-oriented implementation of reform has enhanced irrigation performance and adaptability in the face of growing water stress (Alaerts & Kaspersma 2022). At the same time, groundwater extraction and the resulting subsidence in coastal areas remain major worries that cannot be disconnected from upstream surface water allocations.

The Netherlands (and Flanders (Belgium))

The Netherlands is small but densely populated. Situated in the low-lying delta of the Rhine, Meuse and Scheldt rivers, and benefiting from a moderate, rainy climate,[7] for centuries it had to manage an excess of water, investing in flood protection and large-scale drainage and land reclamation (*polders*). The western part consists of flat peaty and clayey land with high groundwater levels, while the southern and eastern parts are mostly sandy and lie above the level of the crossing large rivers. The Flanders Region (northern Belgium) has a comparable landscape, rainfall, population density and economy, but its incoming rivers also exit the country: it enjoys only one fifth of the renewable water available to the Netherlands. After the 1950s, industry and services started powering their economies, and cities expanded rapidly. Similar to China, in the Netherlands, the main rivers perform other critical functions: they carry one-third of all freight in the country; their flow must evacuate sediment and repel saline seawater intrusion – the largest water 'use' in the country (van Berkel *et al*. 2022); and groundwater levels must be kept high (as peatland risks oxidation and subsidence, and to protect the wooden foundations of about 1 million homes from rot (Deltares 2020)). Here and in Flanders, environmental sustainability was already incorporated in water policy since the 1980s, and no need exists to buy back or re-allocate water. Still, this water is increasingly subject to competition from farmers and urban services.

The Netherlands has a centuries-long record of protecting against water excess and has developed large, dedicated water management administrations. The national government sets overall rules, and its executive DG Water Management manages the coast and main rivers. Twenty-one autonomous Regional Water

[7] The Rhine and Meuse rivers supply over two-third of renewable water, rainfall the remainder (CLO 2020).

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Authorities manage all local surface water issues, water levels in polder compartments, drainage and wastewater management. The nine Provinces are in charge of groundwater and spatial planning, and 11 water supply companies produce and distribute tap water. A four-level priority order for occasional droughts assigns the highest allocation priority to the integrity of dikes, then to vulnerable ecosystems and horticulture, while annual crops, resilient nature and industry come last. Permits must be obtained only for large surface or groundwater abstractions (>150,000 m^3/year) as water is considered plentiful; the State has only an 'effort obligation' to meet any demand. The Netherlands prioritized intensive drainage ('colander country') until a sequence of very dry years (2018, 2019, 2020 and 2022) highlighted unsustainably high demand, pushing the country to adopt a new water management paradigm (MVW 2021; BBG 2022; Respondents 2022, 2025). Now, competitive tensions are emerging. Although the law does not provide a formal right to water, in one instance, 1,400 farmers are preparing a lawsuit against water supply utilities, attributing their 'right' to their historical use. In the same vein, some water utilities can no longer expand production and thus delay connecting new industries and housing development; this awards existing customers a *de facto* 'right' based on historical precedent.

In contrast, in its history Flanders never faced large-scale flooding and drainage problems, so it was never urged to establish strong water administrations. Flanders' growing population and economy pushed its water demand well beyond availability already in the 1980s, raising public and political awareness. Whereas in the Netherlands, Water Authorities can still only issue *ad hoc* blanket temporary withdrawal restrictions, Flanders also regulates small withdrawals more strictly, requires households to store and re-use rainwater, applies a progressive (expensive) tap water tariff, and is creating local farmer groups to retain more water (Respondents 2024, 2025). In the Netherlands, tap water consumption is still high at 125 L/cap.day (VEWIN 2025), while Flanders managed to reduce it to about 90 L/cap.day (VMM 2021). The country's existing collective-action mechanisms are also being expanded (e.g. with a Drought Table – *Droogtetafel*) and re-focused. While trading is not allowed, the sharing of water through exchanging and scheduling is locally encouraged, and new targets to retain more water and incentivize water savings are set (Respondents 2022-2025).

The Netherlands is a country that has just started to transition from a 'wet' country to one that must simultaneously take measures to achieve more secure and adaptable water allocation. The Regional Water Authorities and provinces have started preparing steps to manage this relative water shortage through landscaping, infrastructural and institutional measures: besides more water recycling, per 2026 in several regions permits will become required also for medium-sized and smaller withdrawals with monitoring and enforcement of strict use conditions; withdrawal fees are being raised ten-fold; and campaigns are being rolled out to make the citizenry aware of water shortage (Respondents 2022-2024).

DISCUSSION

Institutional instruments for water allocation

Combining instruments

All countries are applying a combination of allocation instruments. Although intended to be mutually supportive, they are often uncoordinated and sometimes counter-productive (cf. Seijger & Hellegers 2026). For example, many countries subsidize irrigated agriculture without capping net water use, and Agriculture Agencies and local governments dole out pumps to irrigators irrespective of water allocation plans. Economic instruments are universally applied but need to be designed carefully; prices and tariffs incentivise savings, but price elasticity may be limited, notably in agriculture. Overall, water is priced far too low. Collaborative action also occurs universally in informal as well as formal contexts, and can mitigate local competition, but also risks

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being captured by elites and unresponsive to basin-wide competition and environmental interests. Alaerts *et al.* (2026a) offer a more exhaustive review of instruments and how and to what effect these are applied in the case countries.

Regulations on rights and permits are key to any functional allocation arrangement; they enunciate the frames to award rights and entitlements in the form of concessions, use permits, licenses, etc. Economic instruments such as pricing and many collective-action arrangements depend on the existence of such permits or rights. The evolution over the past 20–30 years in Spain, Australia, Mexico and Chile shows that rights and permits are increasingly becoming subject to conditions regarding purpose and location of use, validity period, and conditions for discharge, extension, forfeiture or penalty (in case of non-use or non-compliance), and transferability and trading (Müller *et al.* 2026). Secure access to water over long time periods is desired by all existing water users, while water managers (and prospective users) also seek adaptability. Resolving this fundamental trade-off by determining 'reasonable' time periods is challenging. Rules should 'stick' without society getting 'stuck'. The case studies suggest that a validity of 15–25 years offers security as it aligns with typical write-off periods of investments.

Spatial scale

Spatial scale matters in design and application of institutional instruments. At the large scale of country or large basin, the assignment of large water volumes to specific uses supports national policies and the management of large water volumes: supporting regional development (all country cases); maintenance of groundwater (Netherlands, Spain, Flanders and Australia); river engineering e.g. to facilitate shipping, support ecologies or prevent flooding (China, Australia and Netherlands); flushing of saline water intrusion (Netherlands, China, Australia, others); etc. Water volumes and infrastructure tend to be large. Decisions can be guided by economic evaluation of development scenarios but often are political. At the regional scale of a sub-basin or large drainage area, large users – typically both governmental and private actors – divide available water: water supply companies, irrigation districts, power generators, factories, etc. Water has a recognizable value for these competing users, which allows allocation decisions to be informed by approximating financial prices. Finally, also in all country cases, at the local scale individual private end-users are making daily decisions; they may meet each other physically and participate in local social and economic activity, and the value of water to them can be directly translated in financial terms but may also be a matter of survival.

These three scales are interconnected, hydraulically and institutionally, but must be mutually compatible. In all country cases, national governments tend to be more effective at large-scale allocation and struggle with establishing a cost-effective regulatory frame for the regional and local levels. Governments in China, Spain, Indonesia and India (Warghade *et al.* 2026), and most other countries desire to retain stronger control of local allocation processes through administrative regulations or direct political interference.

Trading

Despite concern regarding trading of a critical resource like water in imperfect markets, formalized trading systems of water (use) rights have become mainstream in (large parts of) some countries. In Australia, China, Spain, Chile, Mexico (and the western US), trading aims to provide flexibility while retaining a reasonable degree of security – either in terms of water access or income. Groundwater markets in Pakistan, West Bengal (India) and Bangladesh are widespread and generally advantageous to both sellers and buyers but insensitive to sustainability concerns (Meinzen-Dick 2000; Lountain *et al.* 2021). Tellingly, at local scale in non-industrialized as well as industrialized countries, voluntary trading of groundwater or canal water among irrigators and other users is reportedly very common: e.g. farmers in countries like China, Mexico, Indonesia and the Netherlands, who

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temporarily or permanently do not need the water they are entitled to, may lease their water to neighbours. Such swaps are always based on reciprocity or compensation, expressed as money, barter or social obligation. Still, Hellegers & Perry (2006) argue that water is vital to all life and has, for some functions, no substitute and, thus, carries a 'human right' while nature exerts a strong prerogative as well. In addition, water is associated with many externalities and, if traded, must contend with market imperfections by regulation or compensation.

Countries where, on average, water availability remains adequate, such as the Netherlands and Flanders, traditionally did not apply comprehensive permit-based arrangements; in periods of penury they issued *ad hoc* withdrawal bans. The administrative effort and cost involved are modest; the arrangement is very adaptable for the government but is reactive and adds no security to users (Figure 3, Zone 1). Chile, China and Mexico – middle-income countries – issue water use permits that are fixed (Zone 2). The administrations have relatively weak capacity or mandate to fully monitor and enforce. The administrative effort is higher because of the more comprehensive approach and offers more security to permit holders, but its fixed nature renders it less adaptable. When, in a dry season, water turns inadequate to service all permit holders, local formal and informal institutions must negotiate and agree how to adjust and allocate the 'pain'. Spain and Australia – high-income countries – have well-endowed, capable administrations and adjust water allowances dynamically to actual and forecasted water availability and demand; in Australia, allowances may go as low as 10% of the 'private' entitlement (Zone 3). This arrangement requires a significant administrative investment to government and users but offers more security and adaptability for highly variable hydrological situations where competition is fierce.

Australia, Chile and some western US states maintain a relatively open market; Australia is the most accessible and transparent, yet most strictly regulated by external regulators regarding the trade rules: on transparency, competition, speculation, impact and fraud. Spain and China only allow transactions after approval and

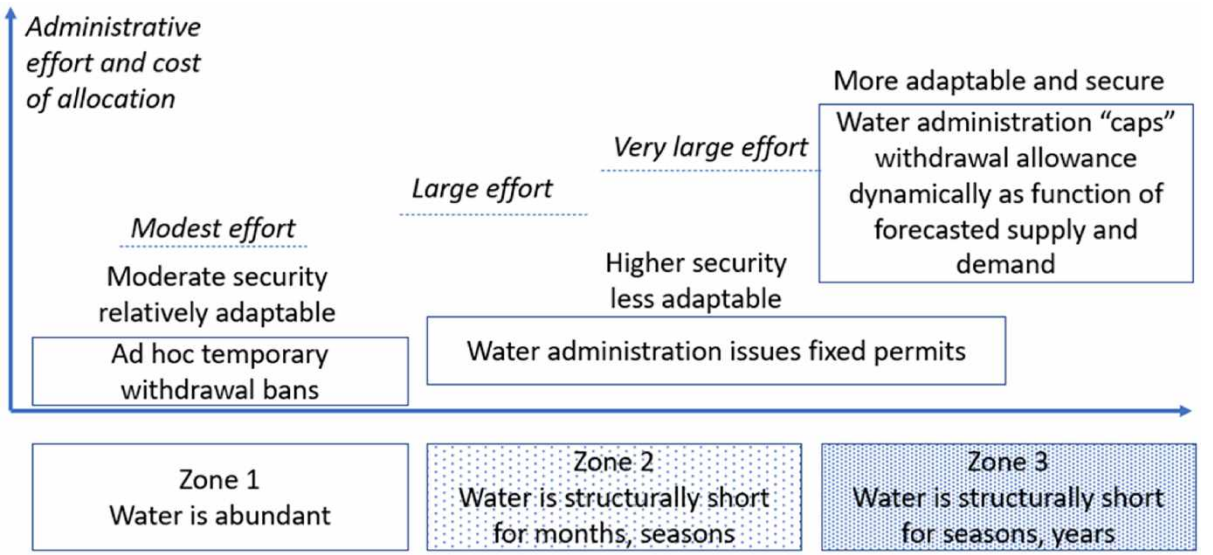

Fig. 3 | Schematization of water withdrawal permitting arrangements under different water stress. 'Shortage' here means with respect to demand.

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supervision of the water administration or local irrigator WUA, and subject to reallocation to higher priority use. Although such restrictions help to control water use, they create 'hysteresis': long delays negating the markets' need for prompt response. Users tend to prefer unconstrained markets as these help address their productivity ambitions better, and, in instances where they 'sell' their right, receive market-conform compensation; in Australia's MDB farmers who are sensitive to drought may then earn more by selling their annual right than by growing their crop (ABARES 2023).

Formalizing the rights favours productivity goals yet raises concerns about sustainability and equity. The Netherlands and Flanders had issued environmental protection legislation already since the 1970s and find it comparatively easy to incorporate them in allocation via their mandatory River Basin Management Plans (EU Water Framework Directive). Spain and Australia recognized these constraints later and were compelled to buy back water rights for these purposes; in principle, they reserve environmental allocations first and distribute the remainder. China, Mexico and Chile, as well as many other countries, are struggling to integrate environmental policies into water allocation procedures. In several other African and Latin American countries, old social and colonial-era divisions in society have tended to assign more water rights to incumbent and financially powerful 'formal' users at the expense of indigenous communities and smallholders.

Path dependency

The longitudinal comparative analysis reveals fundamental systemic shifts in allocation and rights policies over the past four decades in all sample countries. These shifts appear triggered and shaped by similar concepts, and lead to transition pathways that demonstrate significant similarities as well as differences, depending on geo-hydrological, social, economic and cultural factors and legacies shaping the countries' development. These shifts suggest that allocation-and-rights policies will remain subject to further changes, and that any case study must avoid treating the arrangement at a particular juncture in time as 'the' regime.

Firstly, up to about the 1970s, water policies were driven by extensive infrastructure development associated with large and expensive technical water bureaucracies. This is well described for the country cases above but also the USA (e.g. Reisner 1993). This construction paradigm dramatically increased water availability, catalyzing further demand from growing populations that, typically, after the 1970s, started exceeding supply options. The situation turned tenuous from the perspectives of economic development, environmental sustainability and social equity. Secondly, a long economic recession in the 1970–1980s in most economies of the world resulted in unemployment and stagflation (IMF 1986; Kose *et al*. 2020). These drivers combined to lead policy-makers to advocate liberalization of the economy, smaller bureaucracies and a new role for a regulated private initiative. Thirdly, as environmental quality started declining rapidly, citizens and politicians grew aware of the value of ecosystems and biodiversity that were being lost. This took hold already in the 1970 and 1980s in wealthier regions with high population, strong economies and less abundant ecosystems, e.g. in western Europe and the US, and after the 1980s in Australia, southern Europe, Asia, Latin America and later Africa. Between 1980 and 2000, many countries issued modern framework water legislation prioritizing IWRM (emphasizing governance over infrastructure), water as an economic good, sustainability and social equity. They generally also included the economic tenets of 'polluter pays' and 'user pays' as well as a more transparent regulatory frame for water allocation and rights.

The identified key country attributes that account for differences in trajectories are historical water abundance/shortage, presence of legal traditions and the position of private rights (and their enforcement). Traditionally water abundant, the Netherlands was not compelled to introduce rights or concessions in its 2000 Water Act. However, as population and economic activity kept expanding, and triggered by dry years 2018–2022 – revealing that the water system would no longer satisfy all demand – farmers, water utilities,

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industries and local governments started insisting on their historical 'rights' to water. Thus, national and several provincial governments are now exploring wider introduction of formalized withdrawal permits and significantly higher tariffs to manage and reduce demand and facilitate better water use scheduling. In contrast, Chile, Spain, Mexico and Australia – all historically vulnerable to structural relative water shortage in large parts of their territory – needed to establish rights and permitting systems earlier on.

For its 1985 Water Law, Spain built on its centuries-old legal traditions in water allocation and shifted water to the public domain with withdrawal permits issued by existing strong water administrations – now basin-based. On the other hand, Australia, with a penchant for private entrepreneurship and explicit private rights, also for water, deregulated many sectors in 1992, including water. It established a states-led Murray–Darling Basin Commission (re-instituted as a Commonwealth Authority in 2007) and, with the 1994 Water Commission Bill, confirmed the powers of both private users and state water administrations that henceforth would be less executive but empowered to 'cap' the annual withdrawal allowances and arrange for their trade; after 2007 it also invested heavily in environmental restoration. Chile pioneered radical free-market policies already after the 1973 Pinochet *coup d'état*, leading to its 1980 Constitution and 1981 Water Code that expanded private rights to most water resources and allowed their trade, while downsizing the water administrations and their authority (Bauer 1997; Brender 2010). Mexico also started deregulation and adopted IWRM concepts under its 1992 National Water Law, mandating water concessions by its national water administration. China, finally, also recognized that growing competition for water could not be managed effectively and sustainably under communism's strict planned economy. It started transitioning after 1978 to a 'socialist market economy', to great effect. Its framework 2002 Water Act, expanded autonomy of local governments and water users, while also introducing sustainability concepts and selected IWRM principles.

Continuous adaptation and policy learning

Although these broad-based reforms generated significant beneficial economic and social impact, they also seemed able to only partially address other salient complex water challenges. All these newly introduced regulatory arrangements proved subject to further amendment and refinement, guided by a growing body of local and international experience, but also by public pressure. Many of these subsequent adaptations intended to provide more balance between the trade-offs identified above, such as between security and adaptability, and between economic development, sustainability and equity. This balance is often found by strengthening other types of instruments than the dominant institutional instrument in the mix of regulatory, economic and collective-action instruments.

Spain's 1987 concession system offered substantial security to water users but was weak on sustainability (protecting and restoring ecosystems and aquifers) and adaptability. Thus, subsequent regulations (1999 and later) introduced tradability of such concessions, elevated environmental flows to the highest priority (also to align with the EU Water Framework Directive) and established Water Banks to re-purchase water and restore ecosystems and aquifers. Similarly, Australia enacted its 2007 and 2008 Water Laws that established independent Environmental Water Holders and a large buy-back programme to re-allocate water to environmental and social purposes. Whereas Spain was introducing markets yet keeping tight administrative control over trades, Australia, in contrast, started regulating its water trade, deemed too unconstrained, more intensely. In Chile, growing dissatisfaction with the weakly regulated private water rights and aggravating environmental deterioration led in 2022 to a key Amendment of the Water Code to curtail the private concessions and strengthen environmental protection and the administration's oversight. Similarly, China needed to make water more productive and started pilots establishing local WUAs with some management powers and market concepts after 2008.

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In this evolving balancing act, informal practices are often used to make the formal institutional arrangements work. For instance, informal trades between farmers help ease the consequences of larger-scale allocation decisions by river basin regulators in Indonesia. Once countries embark on further formalizations of permits, trading schemes or WUAs, there seems to be a lock-in to paths to further formalization. Once user rights are established, it is difficult and/or costly to return to less formalized systems. In the past decades, several countries have been moving towards more and more monitoring, registration and administrative protocols. This gives a sense of security and transparency, but also increases transaction costs for water allocation. In larger basins and with increasing water shortages, this may be an inevitable development – or at least, our cases suggest that this is the line of recent developments.

Performance: implementation and imperfection

Assessing the effectiveness of a water allocation and rights regime is methodologically challenging as each country has highly specific characteristics and context, and as it yields several impacts on productivity, sustainability and equity that, in turn, are also affected by other policies and events. Effectiveness can be gauged qualitatively as the difference between stated ambition and actual performance. Also, a current regime can be assessed (longitudinally) against its predecessor regime and (transversally) against experience with alternatives in other countries, on the counts of productivity, sustainability, security, adaptability (resilience) and equity. In addition, many countries are starting to quantify how adverse downstream impacts (from externalities, market failures, non-valorization of goods and services, legacies, etc.) not only concern ecosystems but also impede sustainability by degrading water supplies, protein sources (fisheries), incomes and building materials for the impacted communities. Only Australia has instituted a rigorous formal bi-annual review by independent regulators and agencies regarding impact, monopolization risk, influence by external investors, environmental quality, social objectives, etc. Nonetheless, the case reviews suggest that (1) the more recent arrangements with more elaborate allocation and rights arrangements tend to perform better – if implemented well – than earlier ones with respect to economic productivity and, in most cases, sustainability and equity, (2) their implementation is administratively and politically demanding, which may take decades to mature, (3) any comprehensive allocation system is capital-intensive as it requires extensive (telemetric) metering and monitoring, and infrastructure to convey, pump and store water, and (4) substantial imperfections and unintended consequences arise that often are hard to avoid or compensate. The picture emerges that because of the huge variability of local specificities within each country and across time, each arrangement has definite and often large advantages and disadvantages.

CONCLUSIONS

Demographic and economic development combined with catchment deterioration and intensive drainage are the primary potent drivers of relative water shortage under conditions of 'normal', variable climate. Climate change locally also has an effect but will play a more prominent systemic role in the farther future (two to three decades). In many regions, competition for water is yet to be recognized.

Permits, concessions and rights are essential when competition for water is increasing. On the other hand, where water is normally relatively abundant, a light regulatory regime with *ad hoc* temporary withdrawal bans may suffice. Rights and permits are a prerequisite to use most other instruments, to apply tariffs and to allow trade. Although use of permits or concessions looks intuitive, in practice they are complex and expensive arrangements. Permits and concessions need to be based on detailed hydrological, economic and ecological data, require continuous follow-up and updating, and must be metered – preferably telemetrically. This comes at a cost and at the expense of flexibility that can be provided by collective-action platforms, based

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on more abstract underlying principles and rights. Also, informal or black market or speculative behaviour is likely to interfere if the formal permitting or trading system is not systematically enforced – water is just too valuable.

Collective action, stakeholder involvement in decision-making and public awareness are important instruments both for contexts with formalized official allocation arrangements and in traditional settings where such arrangements are lacking. Governments should explore avenues to empower collective-action arrangements and peer control: these assist in fine-tuning and adapting allocation at local levels – that are typically beyond the reach of government – and reduce budget pressure. In conclusion, no arrangement fits all contexts or can be considered a model; each brings advantages and disadvantages that a country must balance for its specific context.

Managing water shortage is a 'wicked' problem: it takes time to agree among the multitude of stakeholders on the diagnosis of water shortage, on the resolution of trade-offs between conflicting policies and on solution paths, yet, by the time of agreement, circumstances will have shifted again. No clear solution exists. Institutional instruments are essential to address shortages by managing demand and are applied universally, but have limitations, require long times to become enacted and effective, assume strong governance, may create unintended consequences that need to be compensated, and work best when used conjunctively.

Roll-out and implementation of policy at field level across the whole territory may well consume one or two decades. This reflects the tenuous task of embedding the regulations and administrative system into the veins of society (including metering, infrastructure, registries, monitoring, forecasting, enforcement, etc.) and the fact that also users must understand, trust and be able to use that system. Even water markets designed to benefit farmers took off only after several years in China, Spain and Australia. However, as implementation of the institutions may be slow, so is that of the alternative measures of infrastructure and land management to enhance supply. Thus, preparation and action are required acutely in order to address situations that may arise in a few decades only.

Many countries have engaged in fundamental reforms since the 1980s to improve their water management and water allocation regime, guided by IWRM and deregulation concepts to shift away from the earlier infrastructure construction paradigm that was proving increasingly unsustainable, inefficient and expensive. These reforms are improving allocation performance compared with this prior arrangement (notwithstanding growing demand), notably with regard to general security and equity, economic productivity and reduction of conflict. Several countries have now also integrated environmental and social protection policies into water allocation arrangements, either because they were early with environmental legislation (such as most western European nations and the US) or because they belatedly issued environmental legislation and established buy-back and 'water bank' institutions to secure environmental water rights and achieve more equity (e.g. Spain, Australia, China). Many other countries are struggling to identify and embed environmental and social sustainability goals in their water allocation frames. Still, the consequences of poor water allocation often remain insufficiently recognized – especially in developing nations (e.g. Indonesia, Mexico and China in our sample) – where a gap appears between the formal institutional ambitions and the actual water allocation practice due to sometimes weaker governance and limitations in the administrative capacity needed for implementation. In general, the effectiveness of arrangements correlates with a country's financial capability and government effectiveness.

Because allocation arrangements affect water distribution in the small veins of society where they contend with great variability in hydrology, landscape, economy, traditions, etc., no 'national' generic arrangement appears able to offer 'perfect' solutions everywhere, all the time. Some of these deficiencies or imperfections are inherent to the nature of institutional and behavioural change (such as slow implementation), while

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others relate to their vulnerability because of the spatially distributed character of water use (such as fraudulent behaviour, free-riding and political resistance).

The transition dynamics suggest that countries face both a crossroads and a convergence. On the one hand, advanced formal allocation arrangements rest on the existence of rights, permits, concessions, etc., but these are very expensive and demanding to establish and manage, and require monitoring and enforcement by a large administration. Some countries (Australia, Spain) invest more to be able to apply concessions that are adjusted dynamically as a function of forecasted supply and demand, further refining allocation allowances. Whereas under moderate water shortage permits allocate 'water' among users, in areas where demand structurally outpaces availability, permits in effect allocate the amount of 'shortage' among users, sharing the effort to deal with the shortage. Thus, a country may elect to forego these expenditures with a simpler system that is reactive and less secure (e.g. the Netherlands and Flanders) or to expend more on an elaborate concession arrangement. Once embarking on more formalized allocation arrangements, it seems more difficult to move back to completely different systems (lock-in).

On the other hand, over the past three decades, several countries have enhanced their allocation regime in an iterative step-wise movement (policy learning) to seek better performance while balancing the three trade-offs. This appears to leading to pathways that have been converging to a hybrid arrangements across three types of institutional instruments: countries that initially stressed the private character of titles, over time shifted water partly to the public domain and 'attenuated' and 'capped' allowances by administrative decision, while countries that initially had a purely administrative arrangement with water in the public domain (e.g. China) evolved towards more indirect regulation and market-based trading. It can be surmised that the Netherlands and Flanders would also feel compelled to develop a comprehensive concession-based system if the current relative water shortage were to deepen, to complement current collective-action procedures among water authorities and water users.

Finally, the cases demonstrate the value of proactive agreement on transparent formalized rules. Proactivity allows for identifying and negotiating interests early on without pressure, avoiding or at least reducing, *ad hoc* political interference under duress of acute drought crises that is vulnerable to lobby interests. The rules, then, may well cover 95% of decision-making, with the remainder relating to priority-setting that does warrant *ad hoc* political decision.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories (https://www.un-ihe.org/water-allocation-and-rights-project).

CONFLICT OF INTEREST

The authors declare there is no conflict.

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