Food and Agriculture Organization of the United Nations

Groundwater governance and the water–energy–food nexus in action:

a global review of policy and practice

SOLAW21 Technical background report

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by
Tushaar Shah
Institute of Rural Management Anand, India

Food and Agriculture Organization of the United Nations

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Abstract

The dominance of insular, supply-side technocratic thinking has posed a major challenge to improving water governance in the face of mounting resource scarcity, which has itself been accentuated by climate change. During the 1990s, global discourse moved from supply-driven sectoral interventions to more holistic approaches to water governance as part of larger socioeconomic and environmental processes. Integrated water resources management (IWRM) emphasized demand-side water management and used prices, participation, entitlements, laws and regulations to strengthen water governance at hydrological rather than territorial units. More recently, there have been pleas for more integrative approaches that link land, water, energy, food, livelihoods, the environment and other spheres – each with its own, often insular, governance structure.

The evolution in global thinking reflects the need to meet growing human needs by innovating approaches that enhance resilience and the sustainability of landscapes, the biosphere and the Earth as a whole. To this end, the water–energy–food (WEF) nexus advocates that society is better off seeking system-level balance rather than maximizing sectoral objectives. The nexus approach has produced prolific analytical literature over the past decade but integrating it into policy and governance faces many challenges.

This review paper explores these challenges by focusing on the WEF nexus in action. We compare the nexus in several water-stressed areas of the world including Iran (Islamic Republic of), Saudi Arabia, Mexico, China, Bangladesh and Gujarat (India), with additional evidence drawn from other places such as Morocco and Punjab-Haryana. We synthesize these case studies to examine the actual state of play in different locations and tease out practical lessons for mainstreaming nexus thinking in water policy and governance. The key conclusion is that specific contexts, contingencies and constituencies drive national and sub-national policies. Directing the outcomes towards the optimal nexus depends on the nature of the state, investment in institution building and, above all, ingenuity in policy design and implementation to overcome resistance to change and strengthen political capital for the leaders who back such policies.

The global challenge of water governance

The past fifty years have witnessed the rise of unprecedented global concern about water scarcity. For centuries, when human settlements grew where water was plentiful, and the rules of water sharing were relatively simple, infrastructural and top-down supply-side solutions dominated water resources management. With burgeoning populations, urbanization, changing lifestyles and agricultural intensification, however, large parts of the world are facing absolute water scarcity. The challenge is expected to worsen under all climate change scenarios (Seckler *et al.*, 1999; Hoff, 2011). In 2015, the World Economic Forum (2015) identified water scarcity as the greatest risk facing humanity. With infrastructure investments to increase water availability rapidly approaching their limits, global debate has increasingly veered towards options for managing demand. The key factor that impedes demand-side management remains the fragmented, insular and territorial nature of water institutions and governance, which are oriented towards infrastructural solutions (Shah, 2016; Agarwal *et al.*, 2000).

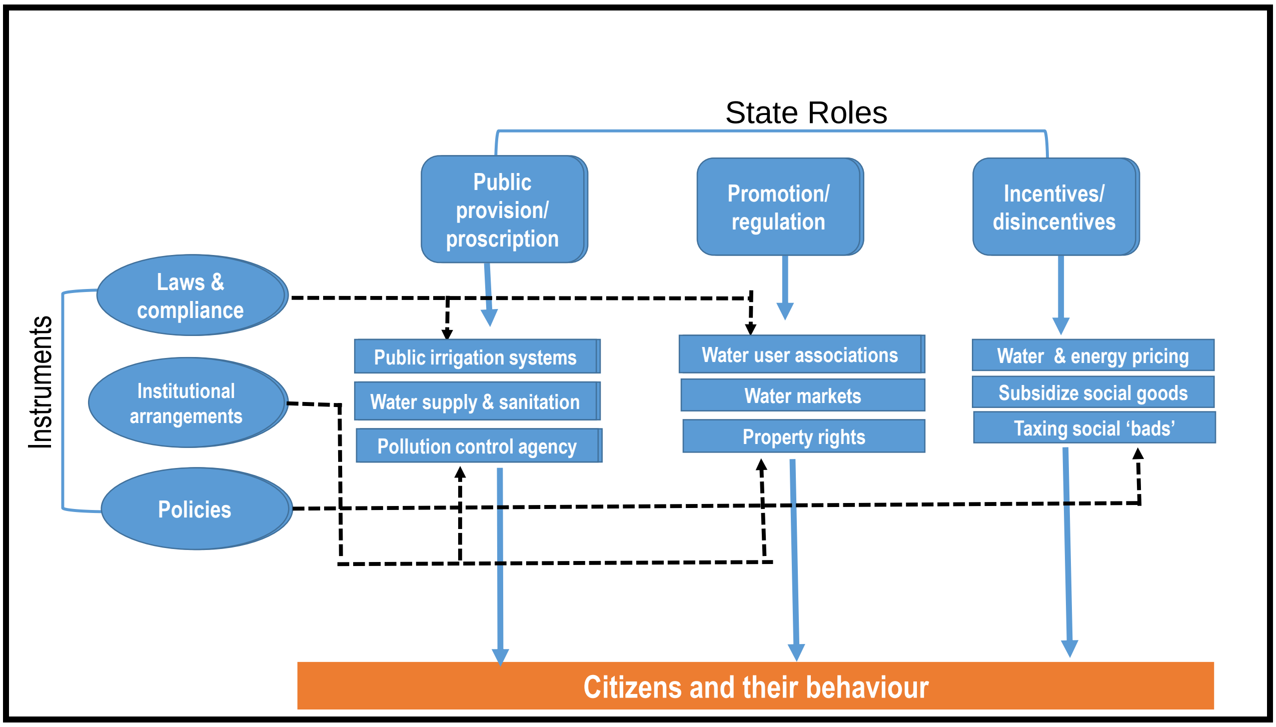
Global attention has thus shifted from sectoral supply-side water management to holistic governance of water as part of larger socioecological processes. The shift emphasizes the role that water laws, policies and institutions can play in meeting the challenge of water scarcity. As the Stockholm International Water Institute (SIWI) observed, "Governing water includes formulation, establishment and implementation of water policies, legislation and institutions, and clarification of the roles and responsibilities of government, civil society and the private sector in relation to water resources and services" (SIWI, 2021). The water governance process creates a framework of rules, policies and protocols to oversee and guide water management, which include, *inter alia,* planning and organizing the mobilization, conservation, allocation and distribution of water. In the business context, management guru Robert Tricker (2015) suggested that governance is about ''doing the right thing'' while management is about 'doing it right.' The distinction equally applies to a society's governance of its water resources.

Figure 1 presents a schematic of the process of water governance in a society. In governing any sectoral economy, the state plays the role of expanding the supply of social goods. It does so by public provisioning (e.g. building dams, canals, water supply and sanitation systems through government departments or municipal agencies); by promoting specific institutional arrangements (e.g. water user associations – WUAs – or basin organizations) or incentivizing private agents to do so on its behalf (e.g. through /subsidies on private irrigation or solar energy or fiscal support to water utilities). The state also limits 'social bads' by taxing them, by regulating the behaviour of agents responsible for them (e.g. depleting or polluting aquifers) or by banning harmful activities completely (e.g. factories polluting rivers or aquifers). In playing these roles, the state generally deploys three kinds of instruments: laws, institutional arrangements (e.g. bureaucracy, markets, property rights, non-governmental organizations [NGOs], WUAs, community organizations, businesses), and appropriate policies.

The speed and scale with which governance interventions impact different categories of population depends on the effectiveness of the various instruments used. For example, the impact of a new law depends upon how vigorously it is enforced. Promoting WUAs or basin organizations only helps if they are properly managed. Pollution is only managed if the regulator has the necessary capacity and will to regulate, ban or tax polluters. In some situations, policies produce faster and stronger impact because they directly reshape the incentives of different actors.

All of the above constitute water governance, and are distinct from the management of water resources, water infrastructure and water services, which entail planning, designing and managing dams, canals, watersheds and basins, water supply and sanitation systems.

Figure 1. Unpacking water governance



Source: author own elaboration

During the 1990s, integrated water resources management (IWRM) emerged as the favourably approach to "doing the right thing" in addressing water scarcity. IWRM, whose roots go back to the United States Tennessee Valley Authority (TVA) during the 1930s, emphasized demand-side management, stakeholder participation, sustainability and the need to integrate water resources management, both within the water sector and as an inseparable part of a nation's social and economic development. The Global Water Partnership (GWP) defines IWRM as: "a process which promotes coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP-South Asia, 2018).

IWRM thinking introduced three key ideas:

- limits to the carrying capacity of the earth and its natural resources, such as water;
- the importance of demand-side management of water; and
- the need for integrated management of water resources as part of broader socioeconomic development processes in a society.

The global community adopted the IWRM philosophy with great enthusiasm. The Global Water Partnership, an international NGO, adopted adopted promotion of IWRM as the mission of the organization. The World Summit on Sustainable Development, at Johannesburg in 2002, adopted the IWRM philosophy and, most recently, the United Nations Sustainable Development Goal (SDG) 6 recommitted its support for IWRM. Countless workshops and conferences have advocated IWRM as a nuanced response to water scarcity.

In many developing countries, donors and multilateral financial institutions made IWRM a part of their water financing strategies. However, what was implemented on the ground in the name of IWRM was often a package of 'silver bullets' that included, *inter alia*:

- a water policy formulation that formally adopted IWRM and declared water as national property and an economic good;
- enactment of a water law that provided a legal framework for IWRM implementation;
- formal acceptance of water as an economic good; enforcement of the 'user pays; polluter pays' principle; and pricing of water services to ensure cost recovery and efficient resource allocation;
- replacing territorial water administration by catchment or basin-level organizations for basin-scale water-land management;
- registering water users/uses and issuing permits, preferably tradable, for water abstraction and use;
- promoting participatory, inclusive and gender-equitable water governance to make water 'everybody's business.'

Starting in the 1990s, IWRM emerged as the ruling paradigm for water sector reform in the developing world. This was strongly promoted by bilateral donors and multilateral funding agencies, commonly as part of their financial assistance to developing economies. Early in the new millennium, however, the realization began to dawn that, while IWRM offers sound guidance for good water governance, it is not sufficient. Researchers found that it was difficult for developing countries to migrate from IWRM theory to practice (Schulze, 2007). Blanco (2008), an IWRM-observer in Columbia, lamented that IWRM meant "paralysis-by-analysis." Many began to wonder if IWRM is a relevant concept or just an irrelevant buzzword (van der Zaag, 2005) and others asked why IWRM had advanced so slowly and typically only at the conceptual level (Najjar and Collier, 2011). The United Nations Environment Programme (UNEP) thought that converting IWRM theory into practice remained "unfinished business" (IWA/UNEP, 2002).

For example, Cambodia, Thailand, Indonesia, Viet Nam and Sri Lanka all translated IWRM into their policies and laws, but their implementation remained tepid (Samad, 2005; Mang, 2009; Yu, 2014; Molle and Hoanh, 2011). In Sri Lanka, with the support of Asian Development Bank, the decision to charge for paddy irrigation water invoked such a resistance that the government quickly backed down (Samad, 2005). In sub-Saharan Africa, scholars and observers reported widespread pushback from communities (Schulze, 2007). IWRM was presented as a theory of action to guide how water governance in developing countries should be reformed. However, given persistent difficulties in operationalizing the theory on the ground, the doctrine began to lose its sheen (Biswas, 2008). A number of researchers (Shah, 2016; Muller, 2010; Giordano and Shah, 2014; van Koppen and Schreiner, 2014) argued that IWRM aims to transform the informal water economies of poor societies into more highly formal systems; but this is a long-term process tied to the overall economic transformation of a society and it is hard to achieve by simply implementing an IWRM 'package.'

Despite the frustrations around IWRM implementation, global discourse on water governance continued to insist that a 'silo' approach to water management was archaic. The clamour for holistic management of land and water became stronger following the land-grab after the food crisis of 2008–9 (Unver and Mansur, 2018). While traditional water management approaches pursued a single-minded focus on efficiency and water productivity, newer concepts sought to situate water governance within a larger setting of ecosystem governance at multiple scales. Based on early lessons from a pilot project in the Kagera transboundary basin, the Food and Agriculture Organization of the United

Nations (FAO) (2017) developed and advocated a landscape-based agroecosystem approach as a variant of integrated land and water management.

If IWRM advocated breaking administrative, territorial and functional silos within the water sector, newer frameworks carried integration much further. With growing concerns around climate change, there has emerged a new clamour for “a planetary food revolution” to shift the focus from “productivity first to sustainability first” (Rockstrom *et al*., 2017). While addressing water use in food production, Rockstrom *et al*. (2017) give priority to “managing natural capital for long-term productivity and social–ecological resilience at field, watershed, and regional scales, in agricultural systems that operate within planetary boundaries to safeguard Earth system.” The key challenge, according to the authors, is to feed humanity within “a safe operating space of a stable and resilient Earth system,” which would require achieving: i) net zero emissions of greenhouse gases; ii) very low or zero expansion of agriculture into remaining natural ecosystems, while restoring others that provide vital ecosystem services; iii) zero loss of biodiversity; iv) drastic reduction in excessive use of N and P (recycling nutrient flows); and v) major improvements in water productivity and environmental water flows.

Water–energy–food (WEF) nexus: A new approach?

As mentioned above, operationalizing the IWRM philosophy faced many challenges (Giordano and Shah, 2014). Although IWRM theory emphasizes that water management should be integrated into larger processes of socioeconomic development, many players felt that the package (although not the philosophy) was too water-centric, failing to sufficiently engage decision-makers across closely related spheres such as food, agriculture, energy, environment and climate change. The IWRM package overlooked the fact that unsustainable water use is often driven by policies outside water sector – most often, the energy or food-agriculture sectors.

A 2011 report by Hoff and the report of a 'nexus conference' by the World Economic Forum (2011) argued that the WEF nexus offered a more integral approach to water policymaking in the wider socioeconomic context:

> "Many global challenges, though interconnected, have been addressed singly, at times reducing one problem while exacerbating others. Nexus approaches simultaneously examine interactions among multiple sectors… (N)exus approaches can uncover synergies and detect trade-offs among sectors" (Liu *et al.*, 2018).

Hoff's much-cited report showed how a nexus approach can enhance water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance across sectors (2011).

Nexus thinking aims to maximize system rather than sectoral efficiency. It addresses externalities across sectors. According to FAO, **"**The water–energy–food nexus is about understanding and managing often-competing interests while ensuring the integrity of ecosystems" (FAO, 2021). The nexus approach, for example, contrasts the high-water productivity of intensive agriculture with its low energy productivity and the energy intensity of desalination with the water intensity of biofuels. It recognizes that controlling soil degradation can save water and investing in groundwater recharge can save energy (Hoff, 2011). FAO has incorporated the WEF nexus into its "larger mandate of eradicating hunger, reducing poverty and sustainably managing and using natural resources and ecosystems" (FAO, 2014, p.9). It advocates integrated management of land, water and ecosystems in the quest for food security in terms of food availability, access, stability of supply and utilization. In operationalizing this perspective, FAO has focused on evidence, scenario development and response options (FAO, 2014). In the same vein, Flammini *et al*. (2014) developed a protocol for participatory WEF nexus assessment to "inform nexus-related responses in terms of strategies, policy measures, planning and institutional set-up or interventions." The protocol aimed to help 'walk the nexus talk' through a step-wise process for nexus policy-making, combining qualitative and quantitative approaches and linking interventions to context.

The WEF nexus approach was largely viewed as an improvement over IWRM:

> …by explicitly focusing on water, there is a risk of (IWRM) prioritizing water-related development goals over others, thereby reinforcing traditional sectoral approaches. The nexus approach considers different dimensions of water, energy and food equally and recognizes the interdependencies of different resource uses to develop sustainable agriculture (FAO, 2014).

> The WEF nexus paradigm provides the water community (with) specific channels to move forward in interdisciplinary research where integrated water resources management (IWRM) has fallen short …In contrast to IWRM… the (WEF) nexus approach has a clearer scope of integration since it explicitly sets the sectoral bounds (i.e. food, energy, and water resources) of integration, whereas IWRM attempts to integrate seemingly all resources and objectives related to water, which is often subject to institutional barriers (Cai *et al*., 2018).

> The nexus approach aims to identify tradeoffs and synergies of water, energy, and food systems, internalize social and environmental impacts, and guide development of cross-sectoral policies. (Albrecht *et al.*, 2018).

> The nexus approach means that when governments and industries determine policies in one sector—whether it is energy, agriculture or water—they take into account the implications in other sectors. Similarly, policy and planning processes within each sector would account for different scales, from local to transnational (Bird *et al*., 2014).

According to many observers, a key advantage of the nexus approach is the priority it gives to ecosystem services and global warming. It also fits well with the idea of a green economy that maximizes human well-being while minimizing environmental risks, ecological scarcities, carbon footprint and pollution (Hoff, 2011; Allan and Matthews, 2016). Nexus thinking is critical for understanding the socioecological implications of the global annual fossil fuel subsidy at USD 5.3 trillion/year (or USD 10 million/minute) in terms of environmental impact and global warming (Allan and Matthews, 2016). Allan and Matthews (2016) have shown that food supply chains account for 92 percent of the world's water and 20 percent of the total energy; in contrast, non-food supply chains consume 80 percent of the world's energy and 8 percent of global water supply.

While the nexus approach has won wide support, it has faced criticism as well. The approach has a far stronger appeal for researchers than for practitioners and policymakers. Some have argued that there is nothing new or innovative about the concept; it is neither necessary nor useful: "Interactions involving water, energy, and food have been known and studied for many years by scientists and policy analysts" (Wichelns, 2017). Others noted that most WEF research examines models and methods for analysing cross-sectoral interactions rather than policy and practice.

A systematic review by Albrecht *et al.* (2018) of 245 journal papers and book chapters on the WEF nexus concluded, *inter alia*, that: i) less than a third used reproducible methods; ii) nexus methods often fail to capture interactions among water, energy and food; iii) quantitative approaches are strongly favoured; and iv) the approach deploys social science to a very limited extent if at all. Common methods used in nexus research include engineering efficiency analyses, supply-chain analyses, and agronomic soil-plant-water relationships. These fail to fully capture intersectoral interdependencies and interactions. Other works offer input-output based quantitative prognoses of the intersectoral impacts of sectoral policies (Vats, 2019). Most importantly, WEF research often falls victim to disciplinary silos; and only 20 percent combines quantitative with qualitative analysis. Albrecht *et al.* conclude:

> While the WEF nexus offers a promising conceptual approach, the use of WEF nexus methods to systematically evaluate water, energy, and food interlinkages or support development of socially and politically-relevant resource policies has been limited. (2018).

While most of the new datasets and information generated by the nexus approach are very useful for planning and policy-making, their impact on policy is yet to be determined. Despite its limitations, IWRM provided a clear, if unsubstantiated, pathway to water policy-making and implementation. The WEF approach, by contrast, has largely remained confined to promoting 'nexus thinking' with ambivalent, even confusing, signals for practitioners and policymakers. As van Gevelt (2020) points out, "Although our technical understanding of water–energy–food (WEF) nexus dynamics continues to improve, this knowledge has not yet been translated into effective and implementable policy."

This is perhaps not surprising. The challenge of implementing the IWRM package was to break down the silos within water economies: irrigation, WASH (water, sanitation and hygiene, hydropower, groundwater, surface water, large versus small irrigation systems, territorial versus aquifer, watershed and river basin boundaries. Implementing nexus thinking requires breaking many more and larger silos – water, fossil energy, renewables, food-agriculture, poverty and livelihoods, pollution, GHG emissions and the challenge of keeping our consumption of natural resources within the planetary boundaries. Moreover, while IWRM led to a groundswell of field research on new policies and their impact, the nexus approach has generated very little such research. Indeed, there has been surprisingly little effort to understand, analyse and synthesize myriad WEF distortions that pervade national water economies, or to determine why these persist and how to deal with them. In the remainder of this paper, we will explore several country/region case studies, each comprising a WEF dilemma. We will then attempt to reach some conclusions about the drivers of the WEF approach in action.

The WEF nexus plays out in various contexts. Trade-offs in scheduling dam releases for hydropower generation versus irrigation are one example. Water use for cooling in thermal plants is another. Water transpired by biofuel plantations and evaporated by concentrated solar energy generation is yet another. However, our case studies focus on energy use in groundwater irrigation. Groundwater overexploitation for irrigation has emerged as the most significant contributor to water scarcity and insecurity around the world, and energy pricing and supply policies are directly implicated in the unfolding of the groundwater crisis in many developing countries. The case studies are fairly representative of the global scenario since they relate to geographies that account for 75 percent of current estimated groundwater use in agriculture (Siebert *et al*., 2010; NGWA, n.d.; Shah, 2009a).

The key questions are thus:

i) How and to what extent has nexus thinking informed water governance in each of these settings?

ii) Going forward, how can it be used to create nuance and balance in the play of water, energy and food policies at local, meso, national and regional scales?

To summarize each country situation, we used the drivers-pressures-state-impacts-response (DPSIR) framework, a popular tool for exploring human impact on nature and the environment (Maxim, Spangenberg and O'Connor, 2009). We begin by briefly outlining the nexus context to highlight the consequences of silo governance. We follow by summarizing the main drivers that explain how things came to be as they are. We then discuss the governance response and identify lessons specific to the circumstances.

Groundwater and food self-sufficiency: The WEF nexus in Iran (Islamic Republic of)

Nexus context

Iran (Islamic Republic of) has been described as heading towards "water bankruptcy" (Collins, 2017), with a growing dependence for its food production on groundwater over-exploitation. Despite increased investment in dams and canals, FAO estimates show that the area equipped for surface water irrigation in Iran (Islamic Republic of) declined by 15 percent between 1993 and 2007, while the area irrigated with groundwater increased by 39 percent during the same period (Nabavi, 2018). The number of tubewells increased from fewer than 50 000 during the 1970s to over 500 000 by 2006 and over a million by 2016. According to Nabavi (2018), Iran (Islamic Republic of) currently has over 800 000 unauthorized wells, accounting for a significant share of the 50 billion m^3 (BCM) of groundwater abstracted annually. Thanks to this groundwater boom, Iran's wheat output has grown rapidly, but its key farming areas are witnessing a decline in groundwater levels of one metre on average per year (Collins, 2017). Extensive soil salinization, water quality deterioration, dereliction of thousands of qanat irrigation systems and shrinking of canal commands are the direct socioecological outcomes of the boom in tubewell irrigation.

Drivers

Since the Islamic Revolution, Iran (Islamic Republic of) has pursued national food self-sufficiency as a policy objective, the importance of which has grown, in recent years, due to increasingly tough economic sanctions by the United States of America. Three policy instruments – government purchase of wheat harvests at guaranteed above global prices, heavy import duties on grains, and subsidized energy supply for pumping groundwater – have been used to achieve national food self-sufficiency and comprise the overarching governance strategy on irrigated agriculture. In 2016, for example, the government purchased 85 percent of the wheat produced in Iran (Islamic Republic of) (mostly irrigated with groundwater) at a price of USD 405–425/tonnes (MT), far higher than the prevailing global wheat price. In 2015, it imposed import duties on wheat of USD 45–50/MT, which made commercial imports unprofitable (Hogan, 2015). Similarly, owners of irrigation tubewells, which are mostly unmetered, pay just 5 percent of the electricity costs (Collins, 2017). In recent years, there has been a growing concern about extensive groundwater depletion, with increasingly strict measures to control overdraft.

Governance response

Iran (Islamic Republic of) has a long history of water legislation, including laws enacted during the 1940s for the management of *qanats*[1] (Nabavi, 2018). The land reforms of the 1960s changed the qanat institutions in fundamental ways. Since 1960s, there has been a steady increase in the number of irrigation wells and in the quantity of water pumped, which has led to a declining level of groundwater in many aquifers across the country. Under a series of water laws passed between 1966 and 1978, all water in Iran (Islamic Republic of)– surface and ground – became the property of the state. The Ministry of Energy was empowered to issue abstraction permits, regulate water consumption patterns and determine acreage under irrigation, well depths, horsepower of the pumps and their hours of operation. More recent water laws addressed the issue of the many

[1] *qanats* are traditional underground channels, which use gravity to transport water from aquifers to the surface for irrigation and drinking. Much of the population of Iran historically depended on the *qanat*, and areas of population have often corresponded closely to the areas where this system was possible.

unauthorized wells as a measure to promote fair access to water (Nabavi, 2018): water delivered to all agricultural water wells should be metered based on a license, with the Ministry of Energy responsible for paying to procure and install the meters. However, the law enforcement remained a challenge because of its provision that any action on well owners had to be approved by a court judge.[2] A new bill provides groundwater managers with greater discretion in applying fines and penalties for groundwater overexploitation. To take advantage of these new provisions, the Regional Water Utility of the province, a subsidiary of the Iranian Ministry of Energy, started a new project in 2009 to enforce the water law by deploying intelligent energy and water meters (IEWM), which measure energy consumption by electric pumps and use a built-in algorithm to compute the volume of water withdrawn.[3] During 2009–10, 1 250 IEWM meters were installed in groundwater-stressed Esfarayen Basin, a 4 545 km^2 sub-basin of the central Kavir (desert) Basin located in Northern Khorasan province. In 2014, Iran's Supreme Council for Water, directed by the president, mandated installing IEWM in all irrigation wells, equipping all drilling rigs with a global positioning system (GPS), and recruiting hundreds of troops to patrol and inspect the tubewells. These policing mechanisms are the main strategy for groundwater regulation (Nabavi, 2018).

In Esfarayen, where groundwater levels declined by 75 cm per year between 1992 and 2008, water quality deteriorated and poorer farmers were forced to quit farming and migrate to urban peripheries, there was some evidence of improvement, as recorded in a 2011 assessment by the Iranian Water Authority. Groundwater quota enforcement through regular monitoring of the IEWM showed significant behavioural change. There was little tampering with the meters and culprits were forced to pay for repairs/replacements. Meters were programmed to shut off pumping for the three non-growing seasons. Self-monitoring as well as monitoring by the Water Authority encouraged farmers to increase water use efficiency, which had been woefully low at 33 to 37 percent (Jaffery and Bradley, 2018). Annual overdraft is believed to have decreased from 30 million m^3 (MCM) in 2008 to 10 MCM in 2011 (Vaseteh *et al*., n.d.). The annual decline of the water level in Esfarayen Basin is thought to have decreased from 75 centimetres (cm) in 2008 to 28 cm in 2011 and 6 cm in 2013 (Vaseteh *et al*., n.d.). The cropping pattern shifted from barley, wheat and watermelon to high-value crops such as pistachio, Persian walnuts, pomegranates, peaches, spinach and tulips. The spread of modern, water-saving irrigation methods began to increase.

Sustainability prospects

While results of this intervention seem promising in Esfarayen, its impacts elsewhere and prognosis for the future seem uncertain (Vaseteh *et al*., n.d.). The IEWM project did not involve farmer participation. Groundwater quotas issued by the Ministry of Energy and enforced by the Iranian Agricultural Jihad Agency did not take into account the traditional water rights followed by farmers (Jafary and Bradley, 2018). Also, the project provided penalties for wrong-doers, while not having any mechanism to reward water savers. A major risk arises from the extreme political costs of enforcing restrictions on groundwater abstraction (Nabavi, 2018).

[2] Article 33 of the Water Nationalization Act of September 1968 states that "… holders of groundwater use permits are required to install measuring equipment on their wells and, upon request of the Ministry of Water and Power, to submit reports on the amount of water used."
[3] Since it is not in direct contact with water, the meter performance is not affected by water quality. Moreover, several security features make them relatively tamper-proof. The meter enables the farmer to monitor water use and avoid the penalty for exceeding his quota.

Furthermore, financial surcharges and penalties may lose some of their strength as farmers move to high-value crops that deliver high water productivity, making water demand price-inelastic. At the same time, policy makers may not look favourably to large scale shifts away from wheat to high- value crops "because allowing extensive mining of groundwater in the near term is acceptable if it yields the impression of food security and greater national self-sufficiency." Such thinking is evident in the regularization of illegal tubewells (Rahnemaei *et al*., 2013).

As Iranian currency has continued to experience devaluation since 2018, government wheat purchases have become increasingly unattractive for growers. Early in 2020, the government announced a new wheat price that was lower than what had been widely expected.[4] Many farmers have been selling their wheat to the livestock industry rather than to the government. This has led to some tensions between the Ministry of Agriculture, which considers grain self-sufficiency to be the priority, and the Ministries of Energy and Water, which are under pressure to ease water stress. Moreover, reducing wheat cultivation may not ease pressure on groundwater as the cropping pattern shifts from barley, wheat and watermelon to high-value crops such as pistachio. The spread of modern, water-saving irrigation methods has increased and a shift to micro-irrigation encourages many farmers to expand irrigated area with water saved.

Governance lessons

1. Every new technology – such as deep tubewells in this case – gives birth to new institutional arrangements that tend to crowd out pre-existing technologies and institutions. Carefully designed interventions to integrate the old and the new can improve water governance. In Iran's case, new water quotas would have received greater acceptance from farmers had they built upon customary water rights around qanats.
2. Reviving qanats and improving canal irrigation can ease pressure on groundwater resources. However, this does not seem to be a priority for Iran's water professionals and leaders.
3. The Iranian Agriculture Jihad Agency works at cross-purposes with the water and energy ministries. Creating coherence among the objectives pursued by the ministries is critical for improving water governance.
4. Elected political leaders will avoid policy measures that adversely impact farmer interests due to "extreme political costs of enforcing restrictions on groundwater resources which force farmers to live within hydrological limits" (Nabavi, 2018, p. 715).
5. The water saving impacts of new technologies and economic policies are uncertain as farmers attempt to protect their incomes in ways that do not necessarily reduce water use.

[4] https://www.presstv.com/Detail/2019/09/30/607546/Iran-what-farming-buying-prices-government

Saudi Arabia: Food security or sustainable water governance?

Nexus context
Like Iran (Islamic Republic of), Saudi Arabia has long valued food self-sufficiency, given its rapid population growth (3.5 percent per year) and excessive dependence on oil. The global oil crisis of the 1970s heightened these concerns. Lack of renewable water, however, was always a major deterrent to food security in the desert kingdom. Given that rainfall is scant and surface water non-existent, Saudi agriculture depends almost entirely on traditional groundwater irrigation, mostly from non-renewable aquifers that were formed, according to researchers, 600 million years ago (Altukhais and Saad, 2002). The oil boom of the 1970s brought prosperity to Saudi Arabia and new surveys in the early 1980s estimated that the country had some 500 BCM of (mostly unrenewable) groundwater reserves, considerably more than had been previously estimated. These occurrences prompted an ambitious programme to make the desert bloom. A related objective was to settle poor transhumant *Bedouin* communities in productive agriculture. Between 1980 and 2000, Saudi Arabia pursued an aggressive strategy of expanding irrigated food production with the help of liberal government subsidies for groundwater irrigation in general and for growing wheat and barley in particular (Elhadj, 2004). For a brief while, this made Saudi Arabia one of the world's leading wheat exporters but its implications for water security were so severe that after 2000, its rulers were obliged to abandon this path.

Drivers
Saudi Arabia used the same incentive policies as Iran (Islamic Republic of). Between 1984 and 2000, the Saudi Government purchased wheat from farmers for over USD 500 per MT, which was much higher than international wheat prices, involving a subsidy of USD 15 billion for the 16-year period. Subsidies were also offered on the purchase of expensive irrigation machinery and the energy used to operate them. In sum, from 1984 to 2000, Saudi Arbian Government and the private sector invested USD 17.9 billion to double the country's irrigated area from 609 000 hectares in 1980 to 1.12 million hectares in 2000, at a capital cost of USD 35 029 per hectare. The number of deep tubewells increased from 26 000 to 86 000. Water extraction from partially renewable sources climbed from 3.2 BCM in 1980 to 14.3 BCM in 1993. During the 1980–1999 period, an estimated 300 BCM of groundwater was extracted, with a per hectare water use of over 14 000 m^3 per year, two-thirds of which was only partially renewable. While rainwater after evaporation is less than 2 BCM per annum in Saudi Arabia, annual groundwater extractions increased from 4.3 BCM in 1980 to 6.6 BCM in 1996 (Elhadj, 2004). Not surprisingly, an agricultural boom followed, and Saudi Arabia surprised the world by becoming the sixth-largest exporter of wheat (Plumer, 2015).

In the long run, the strategy was unviable in economic as well as ecological terms. Elhadj (2004) estimated that between 1984 and 2000, the Saudi government invested USD 83.6 billion in public and private money (not including various subsidies) to locally produce foodstuffs that could have been imported for less than USD 40 billion. Environmental impact was also important. In the four years between 1997 and 2001, Saudi agriculture exported 12.4 BCM of virtual water in the form of cereals, meat, fruit and vegetables; this was nearly six times the country's domestic water use of 2.1 BCM/year, 75 percent of which could potentially have been reused after treatment. Some experts believe that 80 percent of Saudi Arabia's fossil water deposits were exhausted to support the 20-year agricultural boom. By the close of the millennium, most Saudi aquifers were in a precarious state of depletion, and the country had to invest in 31 massive plants to desalinate seawater to meet half of its domestic water demand (Michaelson, 2019). In the eastern Al Hassa Oasis region, 35 artesian springs had supplied domestic as well as agricultural needs under traditional irrigation since time immemorial. Deep tubewell irrigation began during the late 1970s and, by the mid-1980s, all the natural springs had dried up and tubewell water levels fell to 40–60 metres at a rate of 4 metres per year (FAO, 2009). Some commercial farms saw groundwater levels fall by more than 200 metres. Saline intrusion became endemic and serious in coastal aquifers; and water quality declined in large swathes. In Al Hassa itself, the irrigated area declined from 16 000 to 8 000 ha due to salinization (FAO, 2009).

Governance response

By 2000, Saudi policymakers had recognized the prohibitive cost of food independence and virtual water exports. In 2004, the new Ministry of Water and Electricity was mandated to manage water resources and desalination plants. In 2005, the General Administration for Agriculture and Irrigation was created to manage irrigation projects. A comprehensive set of rules and regulations was created. “But despite the existence of regulations and decrees to control excessive groundwater use, the government has had limited success” (FAO, 2009). Starting in 2015, the government began to reduce wheat purchases by 12.5 percent per year and decided to import all wheat from 2016 onwards (Collins, 2017). However, as in Iran (Islamic Republic of), the Saudi Government is finding it hard to put the genie of groundwater overdraft back into the bottle. Even after reducing subsidies drastically, the decline in irrigation water use has been far less than proportional to the drop in cereal production or irrigated area. Between 1994 and 1999, irrigated area declined by 23 percent, but water abstraction for irrigation fell by only 9 percent (Elhadj, 2004).

Initially, the government disincentivized wheat irrigation and promoted fruit crops. This only deferred the problem since, as fruit trees mature, they will become groundwater guzzlers (FAO, 2009). Moreover, when the wheat-growing area was whittled down, farmers made a large-scale switch to alfalfa for livestock farming, which uses 5–6 times more water per hectare than wheat. As a result, the government relaxed wheat restrictions to curtail alfalfa cultivation. Thanks to a virtual ban on wheat cultivation, by 2018 the wheat area was already down to 10 000 ha or less from a peak of 1.1 million ha in 1993 (Elhadj, 2004). In 2019, the wheat area was allowed to increase to about 90 000 ha to help small and medium farmers that had been forced to reduce their alfalfa irrigation by over 40 percent to reduce groundwater depletion (Reidy, 2019).

Sustainability prospects

Food trade has often been used in global diplomacy. Given Saudi Arabia’s role in global oil trade, it was legitimate for its rulers to seek food independence. A justification for irrigation expansion was the government’s desire to help poor Bedouin farmers to settle down and improve their lot. In 1968, the Regulation for Fallow Land Distribution was promulgated to settle the Bedouins. By 1999, over 600 000 ha had been distributed to over 93 000 Bedouins. However, the bulk of irrigated agriculture has little Bedouin footprint. Compared to Iran (Islamic Republic of) where 18 percent of the population depended on farming in 2013, the *ratio* in Saudi Arabia was around 8 percent (Collins, 2017). In retrospect, there might arguably have been more benign ways to support this group than by endangering future water security for the entire country. Moreover, there is little evidence that Bedouin farmers gained from the irrigation boom. In actuality, according to FAO (2009), it has particularly helped large farming companies holding from a few hundred hectares up to several thousand hectares, most of which are in areas with good quality groundwater aquifers. These companies owned two-thirds of the newly irrigated areas, with Bedouin beneficiaries of the 1968 act owning the remaining third.

Governance lessons

1. Water governance operates through laws, policies and institutions. However, legal and institutional reforms are often compromised or even annulled by pressures and the behaviour of certain actors whose thinking and action are influenced by their particular contexts, interests, and constituencies;
2. Once a farming society is accustomed to using groundwater in agriculture, it is hard to wean it away through techno-economic means;
3. Elite interests in farming tend to be more resourceful and versatile than the poor in relying on and using rules and norms to access water resources; they also offer the toughest resistance to governance improvements.
4. Abjuring the goal of food self-sufficiency has not fully stopped groundwater overdraft in Saudi Arabia

Groundwater governance in Mexico: Governments propose, farmers dispose

Nexus context

Agriculture is the largest groundwater user in Mexico – 18.91 km^3/year out of a total of 31.2 km^3/year – and the driver of persistent groundwater depletion. By 2000, 100 of the 653 aquifers assessed were declared to be overexploited. Not all states are equally affected. For example, all of the aquifers in the Guanajuato are overexploited, with annual abstraction some 40 percent greater than annual recharge, leading to sustained annual falls in groundwater levels of 1.22–3.30 metres. Well depths of 200–400 metres are now common, while depths of up to 500–1 000 metres have been reported. Irrigation pump sizes range from 75 to 300 horsepower. Annual land subsidence of 2–3 cm is reported in Bahio as a result (Scott, 2011).

Drivers

The rapid expansion in poultry, beef, and fresh and processed fruit and vegetable production for exports since the 1960s led to rapid expansion in groundwater irrigation in states like Guanajuato, often with heavily subsidized groundwater pumping for the poor *ejidatarios,* former tenant farmers who were given small plots of land as part of land reforms. Around 2000, the electricity tariff covered just one-third of the actual cost, implying an annual subsidy of USD 592 million for farm power supply at a rate of around USD 1 600 per ha. A major subsidy programme to fund land-levelling, sprinkler and drip irrigation systems, and fertigation improved the field efficiency of water use, but did nothing to reduce the pressure on aquifers, because farmers used the water they had 'saved' to expand the irrigated area.

Governance response

Mexico has among the longest histories of groundwater demand-side management through laws and regulations, the promotion of water-saving technologies, specification of marketable water quotas (concessions), aquifer level user organizations, and energy pricing (Hoogesteager and Wester, 2017). Already back in 1948, Mexico introduced a law to restrict groundwater overdraft and the number of wells in certain areas, called *vedas*, where drilling permits were required. This law was further strengthened in 1972, but its enforcement remained lax and patchy (Scott, 2013; Shah, 2003). Moreover, illegal well owners were repeatedly reprieved by regular presidential amnesties. Between 1948 and 1962, for example, ten veda decrees were issued in Guanajuato and in 1983, the entire state was put under a strict veda. Yet, the number of wells in Gunajuato increased from 2 000 in 1960 to 19 600 by 2000. There was an ongoing tension between the need to regulate groundwater depletion and the need to preserve the farming interests. As a result, veda decrees were announced at the same time as subsidies and credit were offered for drilling, equipment, and electricity for new tubewells. In 1992, the new Law of the Nation's Waters mandated a National Water Registry of newly created private property rights in water. Under this law, a user could not impound or divert more than 1 080 m^3 of water annually, except by obtaining a 'concession' from the Comisión Nacional del Agua (CNA), the federal water agency. All existing and new tubewells were to be registered and assigned a quantitative water right in the form of a concession, much like in Iran (Islamic Republic of). Despite this, challenges persisted.

Against this backdrop, Mexico turned to community-based self-governance through the establishment of technical water councils of groundwater abstractors (COTAS); these were supported by Vincente Fox as the vehicle to create a new water culture during his stint as governor of Guanahuato and later as President of Mexico. The COTAS were to be participatory institutions that would develop and enforce agreements to reduce groundwater abstraction. During the early 2000s, COTAS grew in number and membership; they trained several thousand aquifer users, created a tubewell database, identified irregular wells, and became a useful service window for accessing government assistance, especially groundwater concession titles and 'technification' subsidies for adopting water-saving technologies. However, the role of the COTAS in reducing groundwater overdraft was very limited. They suffered from a lack of coherence and collaboration between states and the federal government. Their representative structure was uneven; large abstractors, like municipalities and large companies, preferred to deal directly with the CNA, bypassing the COTAS. Since agriculture, which accounted for 80 percent of groundwater use in states like Guanahuato, was not adequately represented, the COTAS had little hope of reducing abstractions. They had no authority or resources and no buy-in from most aquifer users, especially irrigators. The only support came from state funding, and years after their establishment, they had failed to emerge into genuine, autonomous, user organizations.

Sustainability prospects

Energy pricing did what the COTAS could not. A substantial rise in farm electricity tariffs during the early 1990s reduced tubewell energy consumption substantially, from 72 GWh in 1989 to 57 GWh in 1992 (Hoogesteger and Wester, 2017); this suggested the power of the WEF nexus as a tool for holistic groundwater demand management. However, in view of minimizing further damage to farmers, the Congress blocked all subsequent proposals to raise farm energy prices. It was only in 2002 under the new Rural Energy Law when the National Electricity Commission began insisting on valid concessions before granting new electricity connections for wells, that the increase in the number of unauthorized wells declined. Not having concessions now meant forgoing the electricity subsidy, two-thirds of the rate being levied on farmers without concessions. Existing tubewell owners were only eligible for subsidized electricity (about 65 percent of the commercial rate) if they obtained a concession. This put pressure on existing tubewell owners to secure concessions and made it very difficult, if not impossible, to drill new tubewells in areas covered by the ban. Given the impracticality of monitoring actual groundwater abstractions by farmers, using concessions to restrict pumping was difficult to implement. However, groundwater volumes were now translated into electricity-equivalents and any electricity used above the 'concession equivalent' was charged at commercial rates. This created a powerful incentive to reduce excess pumping beyond concessional volumes.

This incentive was, however, diluted in 2004 when the government offered an additional 20 percent subsidy, on top of pre-existing subsidies on night power consumption for groundwater pumping. This encouraged a switch to night-time pumping and significantly increased groundwater withdrawals. Moreover, since 2000, farmers have used a politically powerful interest group – *Comité Pro-Mejoramiento del Agro Nacional Guanajuatense* (CPANG) – to resist any further increases in electricity prices. CPANG members began to refuse to pay their bills (Hoogesteger and Wester, 2017). The federal government issued waivers for repayment of unpaid past dues by defaulting farmers and, in 2009, wrote off USD 200 million as drought relief. This made energy pricing useless as a water demand management tool (Hoogesteger and Wester, 2017). On paper, between 2009 and 2013, agricultural groundwater concession volumes in Mexico decreased by 1.96 BCM per year but, in reality, groundwater abstraction as well as unauthorized tubewell connections kept soaring. In 2009, estimated groundwater pumping across the country was 1.36 times greater than concession volumes (Hoogesteger and Wester, 2017).

The federal government, through CNA, also tried to create a market in groundwater rights by buying up concession titles from willing sellers. This however, made things more complicated: many farmers with dry wells sold their titles, and used the money to deepen the wells, and some sold part of their concession but kept pumping as before. Urban developers bought farmers' concessions and drilled in the same aquifer. Without real-time monitoring of groundwater withdrawals by titleholders, the market in titles indirectly resulted in the increased groundwater overdraft.

According to Scott (2011), the long-term outlook points to continued depletion. The solutions to Mexico's WEF nexus, in his view, lie in "increasing agricultural power tariffs, eliminating reduced nighttime tariffs, enforcing legislation linking groundwater extraction to power use, and limiting new power connections for groundwater wells." The key question is whether any of these solutions can pass the political economy test.

Governance lessons

1. Mexico experimented with some very innovative institutional interventions for sustainable groundwater governance, such as COTAS and marketable water rights, which faced important governance challenges in their implementation.
2. Implementing a policy that goes against short-term farmers' interests is extremely difficult as it requires strong political will that is often missing.
3. Creating effective water user organizations requires the active engagement of all relevant actors from water, agriculture and energy sectors.
4. Energy pricing and supply can be a powerful water demand management tool. To be effective, it requires policymakers who are ready to risk losing some popularity.
5. Energy policy gave teeth to water concessions as a means to monitor 'abstraction'against concessions. Its effectiveness was limited when subsidies on nightly power supply were adopted, indicating the necessity of policy coherence (water–agriculture–energy).
6. Poor enforcement, the myopia of political stakeholders, the lure of export markets, and resistance by the farming elite often work against sustainable and inclusive water use.

China: Regime of direct groundwater governance

Context

The North China plains have emerged as one of the world's largest hotspots of groundwater overexploitation (Wang *et al.*, 2019). The region has 30 percent of China's water but produces two-thirds of China's food requirements (Wang *et al.*, 2019). During the past 50 years, the region has come to depend heavily on groundwater for irrigation.

Drivers

Subsidies on energy or equipment have played a far smaller role in China's groundwater boom than in the other countries covered by this review. Rather, high water productivity, easy availability of affordable irrigation equipment, poor canal infrastructure and heavy population pressure on farmland were the key drivers of rapid expansion in groundwater irrigation (Shah, 2009a). Another important driver was the privatization of tubewell irrigation under the Household Responsibility System. According to Wang *et al.* (2005), "privatization of tubewells has affected cropping patterns…(as) farmers move into more water-sensitive and high-value crops."

Governance response

Due to its unique political context, China has contained intersectoral WEF externalities better than many other countries. China implemented the IWRM package, and it never succumbed to high energy subsidies for irrigation. Indeed, many Chinese provinces charged farmers higher electricity tariffs compared to other consumer segments (Shah, Giordano and Wang, 2004). Elsewhere, falling water levels and soaring energy costs for pumping would reduce water demand. Yet, thanks to high farm productivity, Chinese farmers have continued to increase pumping groundwater from aquifers in the northern plains (Wang *et al.*, 2019).

China has also been vigorous in ensuring the full collection of irrigation and energy fees (Shah, Giordano and Wang, 2004). The government incentivized the village electricians to maximize tariff collection, with the backing of the village party leaders (Shah, Scott and Buechler, 2004) and implemented a similar arrangement for collecting irrigation fees (Shah, Scott and Buechler, 2004). It introduced "smart cards" at an early stage of groundwater pumping development to ensure that energy use in irrigation was fully accounted and paid (Wang *et al.,* 2017). While these actions prevented WEF interaction from turning into significant trade-offs, as occurred in Mexico, Iran (Islamic Republic of), Saudi Arabia and India, China has continued to experience growing pressures on its groundwater resources (Wang *et al*., 2019). Faced with growing water scarcity and pollution, evident in declining water levels and deteriorating quality, China has moved to rein in agricultural groundwater demand using a three-pronged strategy: direct regulation, participatory water management through water user associations, and outcome-linked direct funding for local water bureaus (Leshan *et al*., 2017).

- Direct regulation. The quantitative water permits – like Mexico's concessions – introduced by the 2002 Water Law were expected to catalyse trade in water rights but with little success. Since 2016, there have been more vigorous attempts to pilot the permits as well as a new water pricing system, but the transaction costs of enforcing water permits and collecting consumption-linked water price have made direct regulation a challenge in China.

- Participatory water management. Inspired by a World Bank project during the 1990s, China mainstreamed WUAs as a vehicle for water demand management. By 2014, some 834 000 registered WUAs covered around 30 percent of China's irrigated areas. While these have helped to increase water use efficiency and reduce conflicts, WUAs in China remain under the shadow of the village committees, the lowest rung of the communist party organization.

- Outcome-linked-funding of innovative projects. A striking innovation introduced by China has involved direct grants provided by the central government to local governments directly (bypassing provincial and prefecture levels) – for innovative water saving projects and interventions that fit objectives and guidelines provided by the central government. Local governments compete for these discretionary fiscal transfers. Despite some limitations, this policy has promoted some high-tech approaches to agricultural water demand management (Li et al., 2018; Leshan et al., 2017).

One such approach is in the Shiyang Basin (Gansu), where limited runoff results from low precipitation and snowmelt from the Qilian Mountain range. A rapid increase in surface water diversion upstream to meet growing demand reduced water inflow to the downstream Minquin oasis by 80 percent between 1950 and 2003. Minquin county farmers responded by launching a tubewell digging spree, causing significant decline in groundwater levels and generating myriad socioecological impacts. In 2006, the central government approved a Comprehensive Water Management Plan (CWMP), as proposed by Shiyang River Basin Management Bureau (SRBMB), to: i) reduce water consumption in the basin from 2.88 BCM in 2003 to 1.97 BCM by 2020; ii) increase surface water flow to Minquin oasis from 97 MCM to 290 MCM; iii) reduce Minquin county's groundwater abstraction from 514 MCM in 2003 to 86 MCM and reduce the entire basin's annual groundwater use from 747 MCM to 417 MCM over this period.

The experiment was celebrated when SRBMB achieved all its objectives in 2014, well before the target date of 2020. An official evaluation showed that agricultural water-use efficiency increased from 0.53 to 0.58; water used for irrigation reduced from 1.71 billion m^3 to 1.39 billion m^3, and water use per acre of irrigated land reduced from 626.72 m^3 to 430.25 m^3. Water productivity jumped from 1.93 Yuan per m^3 in 2009 to 9.33 Yuan per m^3 in 2015 (Leshan *et al*., 2017).

On the downside, coercive enforcement indirectly contributed to an exodus from farming, with a growing number of farmers leaving agriculture for towns and cities. Thanks to the government policy of 'close the wells, abandon the land,' the farming area dropped by 40 percent from the 2007 levels as farmers moved on to non-farming livelihoods. The farmers in Minquin lost an average of 0.231 ha of farmland per household (Aarnoudse *et al*., 2012; He and Perret, 20120). Between 2007 and 2014, 60 percent of working age-farmers left for off-farm livelihoods; those who stayed derived 43 percent of their income from off-farm sources, up from 26 percent in 2007.

Direct top-down regulation played a large role. The government closed 3 318 tubewells and abstraction was severely curtailed for others. Irrigated area was reduced by 663 000 mu. Growing water-loving onions, corn and wheat was forbidden. A typical household water permit allowed 2.5 mu of irrigation at a rate of 415 m^2/mu. Households with more land could get limited additional water but only for greenhouses and at a steep price. Smart cards with readers were installed on each tubewell to monitor abstraction against quota on a real time basis in the County Water Bureau. Canal water charges increased 2.5 times in seven years and were vigorously collected. Greenhouses and drip-irrigated farms enjoyed 20 and 50 percent discounts respectively. For others, a 'water price ladder' was enforced where water use above the permitted quota entailed steep penalties: 50 percent for an excess of 30 percent over the sanctioned quota, 200 percent for 30–50 percent excess use and 300 percent for an excess of over 50 percent above the permitted quota (Aarnoudse *et al*., 2012, He and Perret, 2012). Attractive subsidies were granted for greenhouses, grapevines and fruit trees.

The central government's provision of CNY 5 billion (USD 786 million) to the CWMP was another major reason for success in Minquin county. This financed the lining of canals with concrete, piped water distribution, subsidies for drip irrigation and greenhouses, and the promotion of medicinal crops, fruit trees, cotton and sunflower. In addition, funds from the Sino-Israel Financial Cooperation were used to install Israeli high-tech automated irrigation systems. The long-term sustainability of these automated systems and their wider diffusion among small farmers are important issues as are the ecosystem impacts of reconstructing concrete-lined canals.

In 2014, 874 WUAs deployed 2 517 water managers and served 308 000 households operating 2.37 million mu of irrigated farmland in the Shiyang Basin. These played a key role, not so much as farmer organizations but as implementers of government policies and programmes. Their chief responsibility was to collect irrigation fees, buy water in bulk and allocate it among members. The director and deputy director of the WUA board (mostly consisting of village committee members) were paid a fixed salary of CNY 3 000–4 000 Yuan and a profit share of CNY 12 000–16 000, depending on the fees collected, irrigated area and their performance. As water manager-in-chief for the village, the director took care of the water infrastructure and served as point person for all water complaints. The director was tasked with ensuring that water fee collections increased from 60 to 90 percent, that water conflicts fell from 10 per village to zero and that water management in general improved. In practice, much of the groundwater governance was done by the water user committee and the local government, while farmers paid the bills and accepted the outcomes (Shah, 2017).

The Shiyang Basin CWMP is widely considered to be an exemplar of successful direct water demand management. While this is true, there have also been some social costs, which were borne by the farmers. It reduced greatly the role of the Shiyang Basin as a key grain-producing region. The programme was implemented in a top-down manner, helped by the WUA directors, who were rewarded for their performance in enforcing permits and collecting water charges. He and Perret (2012, p. 11) concluded:

> This case is a successful model, but not all …regions …can copy these experiences. Government dominated …in the administration domain, but also in market and civil society domains. Government helped to establish the market mechanism through pricing… and helped to establish the self-governance …at village level ().

Governance lessons

1. China successfully showcased effective approaches to controlling and reversing groundwater overdraft. However, the extent to which these can be scaled out within China or replicated elsewhere is an open question.
2. Strong enforcement at the county and village levels made all the difference. With backstopping from the communist party cadres, SRMB intervened deeply in all three water governance roles: provisioning and proscription, promotion and regulation, incentives and disincentives.
3. The social costs of limiting groundwater use may be high; decision-makers will have to balance sustainability and social equity.
4. Even with strong party and village organization, institutional interventions – such as WUAs and markets for water permits – have not always worked as expected.

5. China's unique political system has shaped its water governance. The strong party and state machinery at the village level helps to implement behavioural change needed to achieve the goals of the leadership.
6. The politico-administrative context and ecological contingencies created pressure for the holistic management of water and ecosystems.

Barind model, Bangladesh: Centrally-managed distributed irrigation service

Nexus context

The context for Bangladesh's Barind project is different than for the other geographies covered by this review. Agricultural stagnation and dependence on rice imports were among the key challenges that confronted Bangladesh on achieving independence in 1971 (Boyce, 1989; Palmer-Jones, 1999). The belated adoption of shallow tubewell irrigation during the 1980s, which made possible a bumper crop of irrigated pre-summer (*boro)* rice, addressed both these challenges. Due to budgetary constraints, Bangladesh steadfastly steered clear of providing energy subsidies for groundwater irrigation, despite the debilitating poverty of its millions of small farmers. High energy costs have deprived Bangladesh's agrarian poor from benefiting fully from its abundant water resources (Shah, 2007). Improving irrigation access without introducing energy subsidies has been a challenge. The Barind model in drought-prone (but rainy) northwestern Bangladesh offers an interesting large-scale intervention of holistic, participatory tubewell irrigation development with many lessons for creating a pro-poor WEF synergy.

Drivers

The Barind tract, in the catchment of Ganga (Padma), includes the Rajshahi, Dinajpur, Rangpur and Bogra districts of Bangladesh as well as the Maldah district of West Bengal in India. This large tract with hard red soil has heavy monsoonal rainfall of 1 600 mm (although low relative to 2 550 mm for Bangladesh as a whole). Yet for the want of winter and summer irrigation, its 1.44 million ha of farming areas remained largely unproductive, depending solely on rainfed monsoon crops. After the monsoon, the landscape becomes extremely dry with mud cracks sometimes as deep as 15 metres. Scattered private tubewell owners made hay by trading irrigation for summer paddy for 25 percent or more of the value of irrigated output. During the 1970s and earlier, Barind lagged behind the rest of Bangladesh in agricultural growth and rural development.

Governance response

In 1985, the Bangladesh Government established the Barind Multipurpose Development Authority (BMDA) as a parastatal agency and charged it with implementing the Barind Integrated Area Development Project (BIADP). The project included a diverse array of interventions, such as road development, agricultural extension, electrification, introduction of drinking water and even pond construction. However, the project's experience with government-managed participatory tubewell irrigation has been by far the most innovative, distinctive and impactful.

By the mid-1980s, India, Pakistan and Bangladesh had all tried managing public tubewell irrigation through government corporations or parastatals. These programmes failed, due to bureaucratic procedures, inefficiency, lack of service orientation and poor operation and management. The Barind project became an exception because it established a different participatory management model with following features:

- *Demand-led intervention.* Government tubewells are generally established on sites that favourably groundwater supply. Instead, BMDA followed the demand. Farmers desiring a tubewell had to come together with a minimum command of 30 acres, establish a WUA, pay a token membership fee, and apply for the well. The BMDA staff surveys the property, examines resource availability and installs a tubewell of 0.5–2 cusec capacity, depending upon groundwater conditions. The WUA is responsible for the smooth functioning of the tubewell, for water distribution, operation, maintenance and protection of the equipment.

- *Full cost recovery and pre-paid metering.* Farmers use prepaid smartcards (or coupons) on meters (or in previous years, prepaid coupons) to buy the exact amount of irrigation required. The price covers the full cost of energy, operations and maintenance and establishment costs (but not capital costs which were covered by government) and is 40–60 percent lower than the prices charged by private tubewell owners.

- *Incentivized operators.* One of the group members, often a woman, is appointed tubewell operator and receives a 10 percent commission on irrigation sales. Mobile vendor units (MVUs) for recharging smart card and selling coupons, also largely operated by women, receive a 2.5 percent commission on sales. Evaluations suggest that the system is regularly monitored and vigorously managed. The BMDA officials collect used coupons and monitor meters on a daily basis to record pump usage and tally it with electric meter readings.

- *Technical backstopping.* The BMDA aims to ensure the full use of irrigation assets. A team of technicians is available on call for maintenance and repair.

- *Technical innovation*. To capture groundwater from Barind's peculiar geology, BMDA technicians experimented developed an 'inverted tubewell' capable to extract water from a water-bearing formation of between 90 and 130 feet between two impermeable layers.

- *Efficient service*. To minimize water losses in conveyance, BMDA has invested in replacing open channel distribution with buried pipe networks that effectively reduce irrigation cost to farmers. All BMDA tubewells include overhead storage tanks to ensure domestic water security for households.

- *Sustainable resource management*. Rapid expansion, especially in *boro* irrigation due to BMDA tubewells, has created pockets of groundwater depletion in the hard Barind areas. BMDA promptly addressed these concerns. New tubewell construction was stopped in such areas and BMDA began new irrigation by rehabilitating old canals. The project invested in afforestation, rainwater harvesting, re-excavating derelict ponds and old canals. It also launched extensive campaigns to wean farmers away from water-guzzling *boro* rice to water-saving crops, like wheat, maize, pulses, oilseeds, cotton and spices, and to convince them to convert paddy fields into fruit gardens like mango and guava, which are highly remunerative. BMDA also promoted the alternate wetting and drying (AWD) method to replace flood irrigation of rice, training farmers to use a simple device – a 25 cm PVC pipe or bamboo with perforated side – to gauge soil moisture level and choose the right time for irrigation. Banerjee (2016) in his field visits met farmers who had reduced *boro* rice irrigation frequency from three to two times a month.

- *Groundwater governance regime.* Bangladesh issued a Groundwater Management Ordinance in 1985 to regulate runaway groundwater abstraction, but it remained largely unenforced. As BMDA became a dominant player in Barind's groundwater economy, it issued its own irrigation policy and rules in 2008, which prohibited private tubewells in the command of BMDA, thus enhancing its power to enforce sustainability and operations and management norms on its members. Starting in 2016, when depletion issues came to the fore, BMDA completely stopped new tubewells and refocused its strategy on surface water development, conjunctive use and aquifer recharge. BMDA also successfully controlled the proliferation of private tubewells because of its better service, lower prices and ability to win the trust of farmers.

- *Frugal organization and tight management.* In 2016–17, BMDA's 200 strong technical and managerial staff managed to irrigate one-third of Barind's cultivated land, undertook rehabilitation of ponds, canals and check dams, trained farmers, afforested wastelands and constructed roads. The staff cost was 18–20 percent of gross revenue during 2013-16 and the tubewells generated annual surplus of around 15–17 percent of gross revenue. This is significant when compared to canal irrigation systems and public tubewell corporations throughout South Asia, which recover just 8–20 percent of the operations and management costs from irrigation service fees.

Impact

The Barind project has been prodigious in output, outcomes and impact. BMDA's 15 813 deep tubewells provided irrigation for 496 200 hectares in 2015–16 (Banerjee, 2016) in a largely rainfed landscape where scattered private shallow tubewell owners previously ruled irrigation as water lords. The irrigation cost to farmers under BMDA (BDT Rs.1000–1200/bigha or USD 90–108.8/hectare) [5] is far less than the BDT 2 500–3 000/bigha (or USD 225-270/hectare) that farmers pay to private shallow tubewell owners (Banerjee, 2016). In 2015–16, BMDA served nearly a million farmers. It was responsible for two-third of the irrigated area, serving 56 percent of farmers (see Table 1). The programme's affordable irrigation rice alone benefited its members to the tune of (an estimated) BDT 100 million/year. The actual benefit is even larger because most members would not have access to irrigation since normal tubewells are not very effective in hard Barind pockets. This was possible however, thanks to the use of BMDA's innovative 'inverted tubewells'. BMDA became dominant enough to assume a credible role in groundwater governance.

Table 1. Operating results of BMDA, BADC and private tubewells in the Barind region, 2015–16

	Total electric DTWs	Total area served (electric and diesel) (ha)	Average area served/TW) (ha)	Farmers served	Farmers served/TW
BADC	2 943	82 117	27.9	293 986	100
BMDA	15 319	492 208	32.1	952 504	62
Private	5 678	191 749	33.8	458 156	81
Total	23 940	766 074	32	1 704 646	71

Source: Minor Irrigation Survey Report, 2015-16, Ministry of Agriculture, Government of Bangladesh

[5] 1 USD = 82.64 Bangladesh Taka in 2017; I hectare = 7.5 Bangladesh bigha.

Among the country case studies reviewed for this paper, Bangladesh's Barind project is by far the best example of proactive and holistic governance of the WEF nexus. Despite considerable success, the Barind project has remained underassessed. Kang (2013), a close observer, marveled over "Barind's Three Crop Revolution" (Kang, 2013), and Zaman (2013) called the prepaid metering system "a revolutionary change" (Zaman, 2013). Tubewell irrigation increased Barind's cropping intensity from 117 percent to 200 percent at a time when Bangladesh's national average was 174.64 percent (Jahan *et al*., 2010). In 2014–15, the Rajshahi and Rangpur Divisions that encompass Barind reported higher yields per hectare of paddy in the aus, aman and boro seasons compared to Bangladesh as a whole (BBS, 2016). The institutional arrangements are incentive-compatible and create supplementary jobs. The BMDA dealers supplement their income through commissions on coupon sales and recharge of cards. Farmers, many of whom are women, double up as tubewell operators and earn supplementary income through a 10 percent commission.

The fact that BMDA has succeeded over the past 35 years in creating a new groundwater irrigation economy and managing it sustainably and equitably is an enigma. The BMDA board is chaired by a farmer-politician and, according to Banerjee (2016) who interviewed him, he wants BMDA to pursue the mandate of holistic, sustainable pro-poor governance of groundwater irrigation even more vigorously.

Governance lessons

1. BMDA harmonized context, contingencies and constituencies to create an innovative water governance regime. The Barind model is replicable in landscapes at early stages of groundwater irrigation development.
2. BMDA succeeded as a centralized provider of decentralized irrigation services. Many groundwater parastatals in India and Pakistan were created with the same objective but were not successful mainly due to bureaucratic procedures, inefficiency, poor service and the inability to compete with private irrigation service providers.
3. The Barind project has achieved similar results as the Shiyang River Basin Authority in China in terms of demand management, but without the social costs produced by the latter.
4. The Barind project's success was also due to strong support from the political class for the development of a holistic water governance regime.
5. Centralized provision of irrigation services can achieve social ownership and control over water in ways that laws nationalizing water could not achieve in countries like Iran (Islamic Republic of) and Mexico.

Gujarat's Jyotigram scheme: An indirect route to holistic water governance

Context and drivers

Gujarat presented a groundwater governance challenge for some 1.8–1.9 million km^2 of semi-arid landscape in northwestern, western and peninsular India. Over the past 50 years, South Asia –particularly semi-arid western India, and Balochistan and Khaibar Pakhtunwa in Pakistan – has provided the background for significant trade-offs played out between energy subsidies and groundwater use. It started with a policy to expand irrigation by exploiting aquifer storage, which then appeared to be inexhaustible resource, and in time resulted in significant socioeconomic and environmental consequences. In terms of people, land and water volumes affected, the play of the nexus in South Asia has had impacts that are orders of magnitude larger than Iran (Islamic Republic of), Saudi Arabia, Barind and Mexico combined. In this section, we summarize seven of the key impacts of the WEF nexus in the region.

Food production and agrarian livelihoods. Electricity subsidies encouraged private investment in tubewell irrigation on a massive scale, accelerated groundwater irrigation, stimulated high tubewell density (tubewells/1 000 ha), ensured high operating costs of average tubewells and, in general, boosted food and livelihoods security at household and national levels. The subsides resulted in vast area being brought under irrigation (Shah, 2009a). Indian data show that: i) districts with high groundwater irrigation have higher than average value of crop and dairy output per hectare of net sown area; ii) some of the most productive agricultural districts have intensive groundwater irrigation; iii) intensification of dairying and livestock production is strongly associated with intensive groundwater use. Groundwater offered better drought resilience and ended famine in South Asia. By enhancing food and livelihood security for the poor, it prevented social unrest, helped farmers to intensify and diversify land use and increased the carrying capacity of the agricultural economy (Shah, 2009a).

Water markets. Low-cost energy supply in water-abundant areas created highly competitive, informal pro-poor water markets, such as in central Gujarat (Shah, 1993) and for electric tubewells in West Bengal (Mukherji, 2007). Millions of marginal and tenant farmers in South Asia depend heavily on purchasing irrigation services from tubewell owners. In areas where tubewell owners depend on expensive diesel to pump groundwater, as in eastern India, Nepal terai and Bangladesh, high diesel prices create monopoly water markets, with buyers paying 25–30 percent of output in water prices (Shah, 2009a; Kishore *et al.*, 2015). Tubewell owners in these areas often force marginal farmers and tenants into disadvantageous tenancy contracts, as recorded by Shah and Chowdhury in West Bengal (2017). Many have argued that electricity subsidies only benefited wealthier tubewell owners (Howes and Murgai, 2003; Shah *et al.*, 2020). However, marginal and tenant farmers would have been far worse off in the water markets without subsidized flat tariffs (Shah and Chowdhury, 2017).

Inefficient use of energy and water. Since groundwater is not priced in South Asia, energy prices convey the scarcity value of both energy and water. In Indian Punjab and other states where energy is supplied free or at heavily subsidized cost, farmers use energy and groundwater as if they had no economic cost (Modi, 2010). In contrast, in much of the Ganga Basin, which is flush with groundwater, high diesel prices force small farmers to use less irrigation water than is beneficial in private and social terms.

Electricity industry. In many Indian states, the electricity used in groundwater irrigation is 25–30 percent of total electricity consumption in the economy (Shah 2009a,b; IDFC 2012; Monari 2002). Here, power subsidies cause financial drain and imperil investment in energy development (IDFC, 2012). Subsidized energy supply to farmers also encourages rampant theft by non-farm users, who are otherwise subject to higher tariff rates (Shah and Verma, 2008). It also imposes a tax on honest commercial and industrial users, who pay unduly high power tariffs to cross-subsidize irrigation (Monari, 2002; World Bank, 2001). Maharashtra State, for example, charges the industry USD 7.15/kWh to cross-subsidize free power to farmers. The high tariff is a significant competitive disadvantage while attracting investment in industries.

Groundwater depletion and CO2 emissions. In the absence of farm power subsidies, "sustained groundwater over-draft tends to be self-terminating" (Vaux, 2011) as the rising cost of groundwater irrigation forces farmers to switch to rainfed farming. With free electricity supply, farmers most often engage in competitive deepening of borewells to chase falling groundwater levels. Since they can keep doing this by replacing small pumps by bigger ones, they show little enthusiasm for groundwater recharge to arrest resource depletion – except in hardrock aquifers where groundwater runs out before free energy does. Power subsidies have also created asymmetries between cropping patterns and water resource endowments. Water-constrained Punjab began growing water-guzzling rice in vast areas just as drought-prone western Maharashtra emerged as a sugarcane hub of India. Finally, the intensive use of thermal electricity and diesel in pumping has increased the carbon footprint of groundwater irrigation to 5–6% of the total for India and deep tubewells have a lion's share in this (Shah, 2009b; Nelson *et al*., 2009).

*Public and community irrigation systems.*_Farm power subsidies are an important reason for stagnation in canal and tank irrigation systems in many parts of South Asia (Shah, 2009a) in the same way they have marginalized *qanats* in Iran (Islamic Republic of). As water extraction mechanisms WEMs enjoying free or subsidized electricity proliferate in command areas of public and community irrigation systems, farmers stop demanding quality irrigation services from canal or tank managers, which over time leads to decline and decay. Deteriorated canals become inefficient recharge canals while irrigation occurs through tubewells, as evident in Indian Punjab and Haryana. These were largely canal-irrigated until the 1960s but are predominantly tubewell-irrigated today.

*Political gridlock.*_By far the most pernicious fallout is the emergence of political gridlock that makes subsidy reduction or rationalization extremely difficult in states like Indian Punjab, where massive private tubewell investment was stimulated by energy subsidies in the past. West Bengal and Bangladesh, which began tubewell electrification later than states in western India, could both meter tubewells and charge farmers a commercial tariff when groundwater irrigation was beginning (Shah *et al*., 2008). Elsewhere, this was not so. By the time the environmental impacts of subsidies became visible, it was politically difficult to change the policy.

If the Barind project in Bangladesh and the Shiyang Basin Authority's work in China are examples of direct instruments of groundwater governance, the Gujarat experiment presents an indirect instrument of holistic groundwater governance. By definition, an indirect instrument that skirts difficult direct decisions – such as metering tubewells, charging commercial energy prices or banning new tubewells – is easier to implement but is likely to produce similar outcomes, albeit on a smaller scale. Because it does not act directly on the key problem, it is sometimes referred to as second-best. In executing such a strategy, Gujarat acted in the energy sector to produce sweeping changes in the water sector.

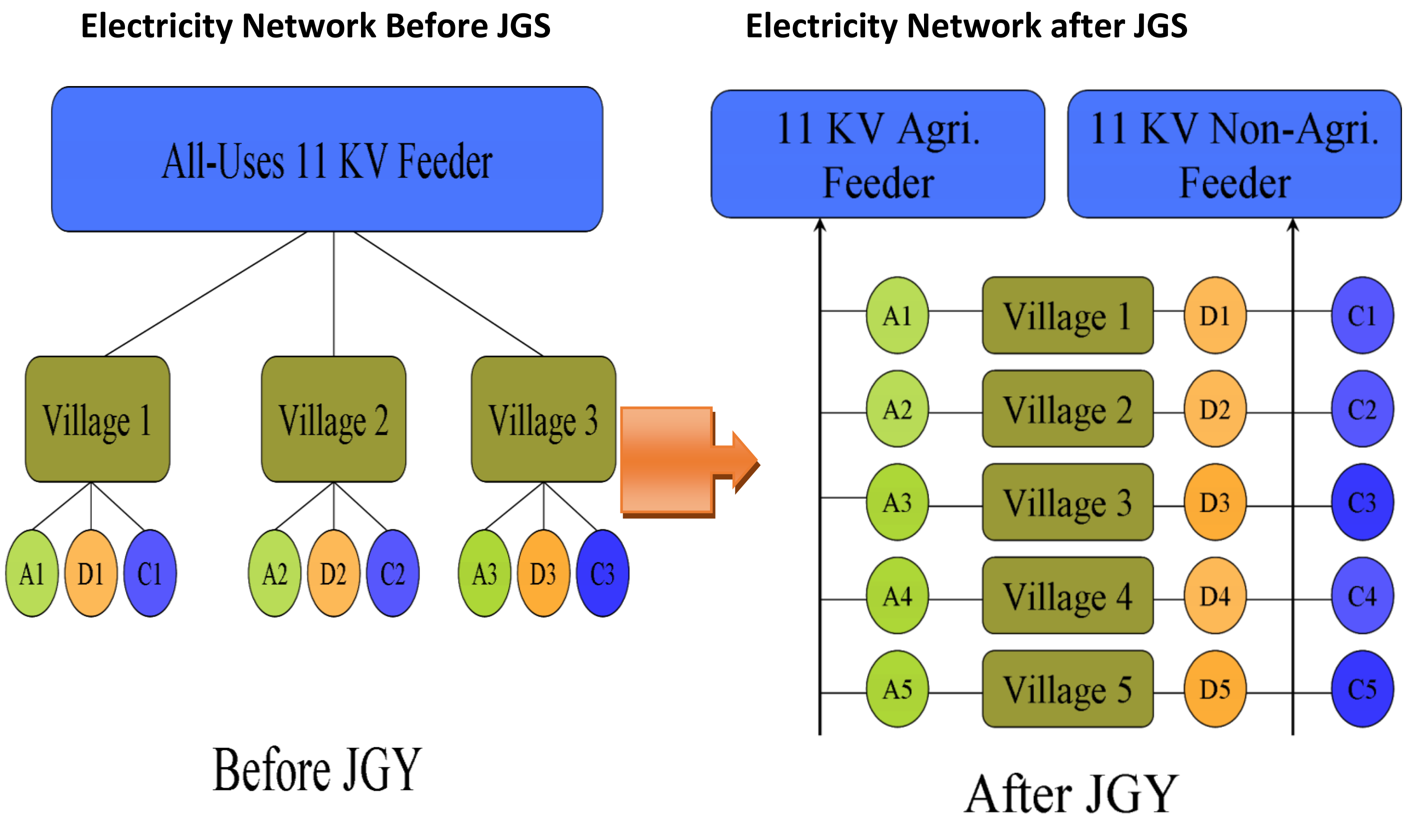
Governance response

In 2001, as the new chief minister of western India's semi-arid state of Gujarat, Narendra Modi tried, with some success, to implement a nexus solution to groundwater managment. He had inherited a state with a government electricity monopoly, an electricity distribution network in advanced state of disrepair and a groundwater-irrigated agricultural economy facing persistent declines in groundwater levels in vast areas. His instinctive move was to meter tubewells and charge farmers tariffs linked to their energy consumption. However, he was surprised by the scale and stridency of resistance from farmers who not only rejected metering but also demanded better quality power supply.

Around 2000, a group of researchers argued that metering tubewells and charging commercial tariffs to farmers would impose high political costs and that a second best, but acceptable, option might be the 'intelligent rationing' of quality farm power supply. Their argument came in four parts: i) the prevailing system, which provided 16 to 18 hours of poor quality rural power per day at subsidized rates, was wasteful and reduced the wellbeing of farmers and non-farm rural electricity consumers; ii) the farmers' demand for electricity was derived demand for irrigation water and as long as farmers received sufficient electricity during 40–45 days of peak irrigation demand, they would be willing to accept reduced hours of supply during the remainder of the year; iii) improving the quality of power supply by improving voltage, minimizing interruptions and proper maintenance of the distribution network would increase farmer acceptance of rationed supply; and iv) rationing farm power supply would reduce aggregate subsidy burden and cap groundwater withdrawals without hurting farmer welfare (Shah *et al*., 2001; Shah, 2009).

In 2002, Modi was elected to the Gujarat Assembly based on his commitment to provide round-the-clock uninterrupted electricity supply to villages, something that no Indian state had yet achieved. Doing this without controlling tubewell pumping would have been disastrous for electricity utilities as well as groundwater aquifers. The only viable way forward was to ration energy supply to tubewells. In 2003, he launched *Jyotigram* (Lighted Village), a campaign to physically separate agricultural electricity feeders from non-farm rural feeders by rewiring the rural power grid in 1 000 days. Modi's leadership skills were proven when Gujarat completed this task between 2003 and 2006 at a modest cost of USD 250 million. The campaign affected over 9 000 rural electricity substations, 18 000 villages, 40 million people and 3.5-4 million hectares of irrigated land. This done, the government announced eight hours per day supply to tubewells on a weekly roster. Every village would receive eight hours during the day for one week and at night in the following week. For the first time ever, around-the-clock three-phase power supply was provided to all non-farm users – homes, schools, shops, cottage industry, institutions. During that period, the electricity utility was reorganized and modernized; power generation capacity was ramped up; and the power distribution network was thoroughly overhauled.

Figure 2. Gujarat: Feeds Separation under Jyotigram Scheme



Source: IWMI, 2011.
https://publicadministration.un.org/unpsa/LinkClick.aspx?fileticket=YfWMSyZ62TE%3D&portalid=0&language=en-US

Evaluations and studies after 2006 showed Jyotigram to have been a resounding success on many counts. Gujarat became the first Indian state with around-the-clock supply of reliable and uninterrupted power supply, leading to massive improvement in quality of life and rural economic activity. Farmers begrudged the reduced hours and nightly power supply during half the weeks, but surveys showed they were happy with improved voltage, timeliness, minimal interruptions and, in general, the better quality of their power supply (Shah and Verma, 2007). Farmers in groundwater-stressed northern districts accepted the rationed power supply as a hidden blessing: without power rationing, they faced totally depleted aquifers in a few years. All new tubewell connections issued after 2006 were compulsorily metered (though with a subsidized tariff); and old flat tariff connections were subjected to a 120 percent hike in flat tariff/HP*. The finances of the power utility turned around: in 1999-2000, it had losses of USD 550 million; in 2006, it turned in a small profit. Since then, Gujarat's four power distribution companies are among the few companies in India that make profits year after year. Between 2001 and 2006, aggregate electricity consumption in tubewell irrigation fell by 37 percent from 15.7 billion kWh to 9.9 billion kWh. Yet instead of suffering, Gujarat's agriculture experienced a boom. During the early 2000s, when the agricultural GDP of India was growing by 2.9 percent year, Gujarat's farm GDP grew at 10 percent per year. Jyotigram won Modi the 2007 state election as well. But Jyotigram's ecosystem impacts were heightened by a complimentary strategy that Modi had inherited but scaled out widely.

Over half of Gujarat lies above hard-rock aquifers with limited storativity. Since the late 1980s, at the behest of gurus with mass followings, religious organizations, non-governmental organizations (NGOs) and philanthropies, these areas witnessed a popular water conservation and groundwater recharge movement (Shah, 2000; Shah, 2009). In 2007, the government of Keshubhai Patel began to lend financial support to this community-based movement. When he came to power, Modi hugely expanded and streamlined government support to the groundwater recharge movement. By 2008, 113 738 check dams, 55 917 *bori bandhs,*[6] and 240 199 farm ponds had been constructed by communities, in addition to the 62 532 large and small check dams constructed by government machinery (Shah *et al.*, 2020). Had Gujarat inherited Iran's *qanats,* there is little doubt that Modi would have launched a massive campaign to restore them in support of the burgeoning tubewell irrigation economy. Studies have shown that these hundreds of thousands of decentralized structures – check dams, percolation ponds, recharge wells, etc. – increased groundwater availability during dry seasons and made Gujarat agriculture more drought-resilient.

The demand-side intervention of Jyotigram and supply-side intervention through the recharge movement makes Gujarat the only Indian state where the groundwater situation has steadily improved in the new millennium

What happened in the aftermath of Jyotigram's success is an indication of the trade-offs between people and eco-systems that policymakers face all the time. One downside of Jyotigram was that it hardened village-level water markets (Shah and Verma, 2008; Shah and Chowdhury, 2017). Studies show that power rationing reduced tubewell water availability and raised its price for resource-poor marginal and tenant farmers that depended on purchasing irrigation services (Shah and Verma, 2008; Shah *et al.*, 2008). The Modi government took this feedback seriously: to help the poor, it launched a special scheme to issue new electricity connections for small pumps for schedule case (SC) and schedule tribe (ST) farmers, some of the poorest in Gujarat. Modi's successor went further. In December 2019, Gujarat's current chief minister issued a full-page newspaper advertisement announcing the pro-poor initiatives of his government, including the issue of 463 000 new tubewell connections issued in just past 4 years (taking Gujarat's total electric tubewells to 1.6 million). Over time however, this measure reduced to some extent the effectiveness of energy rationing to limit groundwater draft and brought to the fore new tensions between the goals of saving water, reducing losses of electricity utilities, containing carbon footprint and providing support to the poor.

Governance lessons

1. Gujarat achieved ecosystem impacts similar to the Barind project in Bangladesh and the Shiyang Basin project in China – although on a much larger scale – by devising a regime of indirect instruments that worked around resistance to limiting groundwater abstraction.
2. Gujarat's strategy of intelligent power rationing and decentralized groundwater recharge reinforced each other to magnify ecosystem benefits.
3. Modi accumulated political capital by successfully projecting the Gujarat impacts as some of his government's key achievements. During the first 15 years of the new millennium, Gujarat's agricultural economy grew at a high compound annual growth rate of 9 percent per year, implying that improving groundwater

[6] Bori bandhs are low-cost check dams made with sacks full of sand.
HP Himachal Pradesh

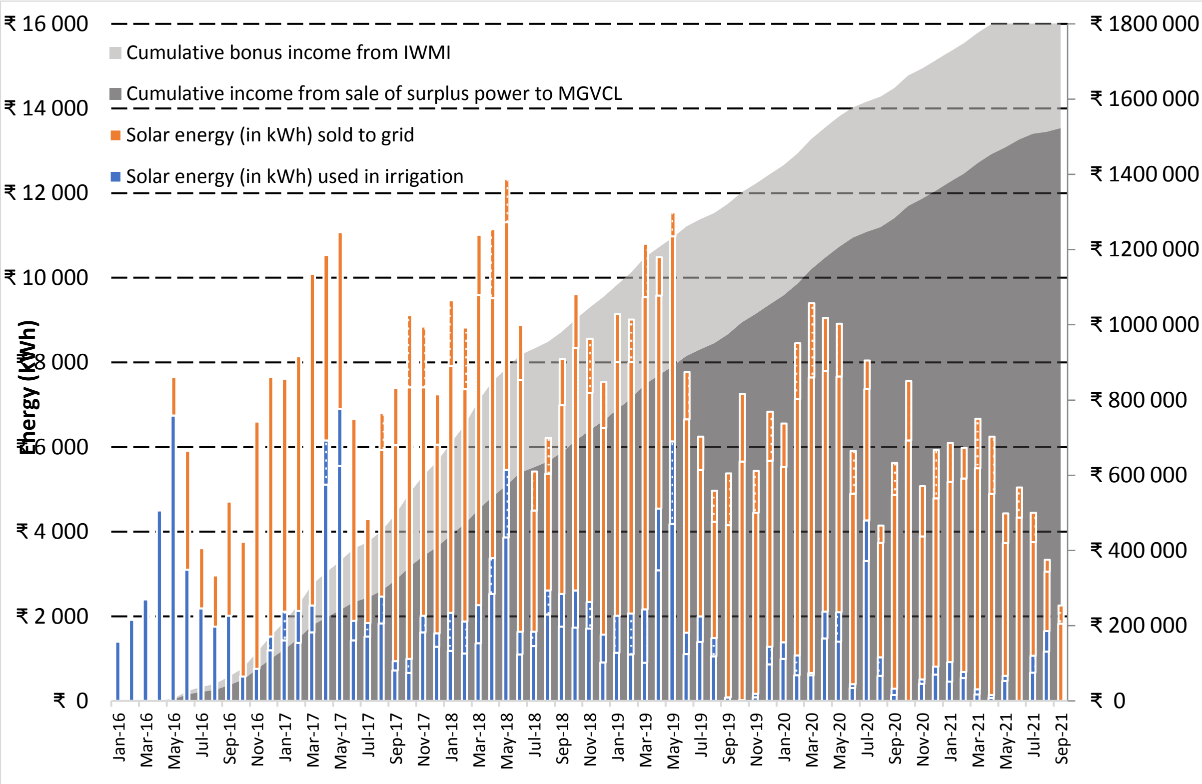
sustainability had not imposed any cost on livelihoods, as occurred in the Shiyang Basin.
4. In terms of scale – area, number of tubewells, farmers affected and volume of groundwater – Gujarat's groundwater governance reform produced by far the largest impact of all the case studies covered by our review.
5. Feeder separation was replicated in Punjab, Haryana, Madhya Pradesh and other states, but as a 'technical fix' without complementary water interventions and, as a result, produced limited impacts. This highlighted the critical importance of holistic interventions.
6. Gujarat's programme to use solar pumps for groundwater governance

Context

A near doubling of tubewell connections – issued to the poorest people among Gujarat's peasantry starting in 2008 – made irrigation access equitable, but increased pressure on groundwater as well as on the finances of the electricity companies. Having succeeded with Jyotigram, the policymakers began to look for other ways of reducing the present and future farm power subsidy burden. One opportunity was the arrival of solar irrigation pumps (SIPs). Every grid-connected solarized tubewell meant a reduction in the annual power subsidy burden in the order of USD 750–1 000 for a long time to come. In the groundwater-stressed western states of India, electricity utilities began promoting SIPs to reduce their subsidy burden on grid power supply to tubewells. Capital cost subsidies on SIPs, ranging from 60–95 percent, were offered to applicants that had been long waiting for a grid power connection (Shah *et al*., 2018). Once installed, the pumps offered reliable daytime power, given India's high insolation for over 320 days per year. In many states, high diesel costs and poor-quality nightly power supply are seen as obstacles to farmers but are the only check on unbridled groundwater pumping. By offering reliable daytime free power, SIPs could exacerbate the pressure on groundwater resources (Kishore *et al.,* 2014; Gupta, 2017; FAO, 2021). Gujarat was particularly worried. Issuing numerous new tubewell connections had eroded the rationing role of Jyotigram. The daytime power supply offered by SIPs increased the annual hours of usable power supply compared to grid connections, which deliver difficult-to-use night power supply half of the year.

In 2015, a group of researchers in Gujarat piloted a village-scale model to explore if farmers could be persuaded to 'grow' solar energy as a cash crop (Shah *et al*., 2017a; Shah *et al*., 2019). They started with the proposition that the demand of small farmers for water is a derived demand for food, income and livelihoods. Solar energy generation requires land, and farmers own half of India's land. If they could use their land to grow solar power to irrigate their land and earn income by selling surplus solar energy at a remunerative price, it might incentivize water and energy conservation. In a pilot experiment in Dhundi, a small village in Gujarat, 11 farmers were provided with SIPs to replace their diesel pumps at a capital cost of USD 147 000 (INR 9 200 000). The farmers formed a microgrid managed by Dhundi Solar Pump Irrigators' Cooperative, the world's first such cooperative (Shah *et al*., 2017b). The state electricity utility connected the cooperative to the 11 kv line, formally accepted it as an independent power producer (IPP) and signed a 25-year power purchase contract at INR 4.63/kWh (USD 0.066/kWh) for pooled energy evacuation by cooperative members metered at a single point. The only condition was that the cooperative members formally surrender their right to grid power connections for 25 years. Figure 3 presents the monthly results of the Dhundi cooperative over 45 months, during which the members sold over 250 000 kWh of solar electricity and earned Rs 1.6 million in net income. The Dhundi farmers used just about 35 percent of their solar energy production for irrigation. Were they not paid for selling the energy, they would have surely used some or all of their solar energy production to irrigate more of their own fields and sell water to their neighbours.

Figure 3. Dhundi SPICE: Operating Results Jan 2016 to Nov 2019.



Source: Dhundi Solar Energy Producers' Cooperative Society, Tri-annual Report 2015-2108. http://www.iwmi.cgiar.org/iwmi-tata/PDFs/dhundi_solar_energy_producers_cooperative_society-tri-annual_report-2015-18.pdf

By 2016, the Dhundi cooperative had become a national media sensation, with hundreds of farmers, electricity utility officials, politicians and bureaucrats flocking to the village to see how marginal farmers could increase their incomes by 'growing' and selling solar energy. A dozen stories about the 'Dhundi model' on national and state television news channels put its success in bold relief. Electricity officials saw the potential to reduce subsidy burden, achieve energy audit and curtail massive line losses incurred by providing farmers with grid power from generating stations hundreds of miles away. Environmentalists raved about clean and green irrigation with a reduced carbon-footprint. Development professionals saw it as a way to put revenues in the hands of the poor, not as a give-away but to meet valuable energy needs. Farmers were happy because they got uninterrupted daytime power for irrigation, additional income for selling electricity and were able to raise high-value shade-loving crops under the solar panels. For years, farmers offered stiff resistance to metering tubewells; now they embraced the meters since they were paid based on metered evacuations of solar energy to the grid. Above all, political leaders saw in the Dhundi model an opportunity to create a new, positive WEF nexus while also reaping political dividends.

Governance response

For the Energy Minister of Gujarat, who spent a half-day interrogating members of Dhundi cooperative in late 2017, promoting solar power as a remunerative crop (SPARC) was an even better idea than Jyotigram for electricity companies, farmers, groundwater, and climate change. In 2018, the Gujarat Government launched SKY (*Surya Shakti Kisan Yojana),* a large pilot scheme to replicate the Dhundi model on 12 400 tubewells on 136 agricultural feeders in 33 districts with a total outlay of INR 7.8 billion (Hindu Business Online, 2018). Sky replicated the basic Dhundi features: farmers would generate their own power *in situ* and receive a 25-year surplus power purchase guarantee at a remunerative price. However, instead of village level microgrid, SKY took a multi-village agricultural feeder as the unit of solarization and established feeder-level management committees elected by SKY farmers. The financial model was different too. Farmers contributed 5 percent of the capital cost upfront. The balance was covered by a 30 percent central government subsidy and a 65 percent loan taken by the state government on behalf of the farmers. The solar energy purchase price – the so- called Feed-in Tariff (FiT) – offered was higher than in Dhundi at INR 7/kWh, however, farmers receive INR 3.50/kWh in cash while the government retains INR 3.50/kWh towards loan servicing. At least 70 percent of tubewell owners must join to enroll the feeder in SKY. The SKY feeder is to be kept live for 12 hours during the day (instead of eight hours during day and night in alternative weeks as in Gujarat). Each SKY tubewell is net-metered. A farmer can use a mobile application to monitor his daily power generation, consumption and evacuation.

The SKY scheme is in the early days of implementation and not ready for even a preliminary assessment. However, electricity utilities can already see the benefits in terms of reduced line losses and subsidy saving.[7] Farmers are happy with daytime uninterrupted power over longer hours. The litmus test, however, is energy use in pumping groundwater. The expectation is that solar farmers on SKY feeders will reduce pumping significantly to enhance their income from energy sales compared to the grid farmers on SKY feeders. Data on 59 completed SKY feeders between May 2019 and October 2019 showed little difference: 2 190 SKY farmers used an average of 246 kWh/HP for irrigation while 908 grid farmers on SKY feeders used 235 kWh/HP. With time and more rounds of payments for energy sales, there will be clear evidence to show whether SKY changes the behaviour of farmers. Because there are no losers, SKY is likely to be scaled out even faster than feeder-separation under Jyotigram and, to the extent that power subsidies have fueled groundwater overdraft in India, SKY can reverse this trend by providing small farmers with strong incentives to conserve water and energy.

Impacts

SKY competes with another model of solar irrigation being implemented in Maharashtra. This model invites private investors to build tail end solar power plants (1-2 mWs in size) on government land to energize an entire separated agricultural feeder. The utility offers investors FiT on total generation, while farmers get free daytime solar power. Surplus power flows back into the grid, which then supplies the deficit. This model, preferred by utilities, will arguably offer them cost savings, upscaling potential and mobilizing private

[7] Between May and October of 2019, the estimated subsidy savings on 59 SKY feeders per HP of solar tubewells were INR 851, INR 1061, INR 620 and INR 1468 for Paschim, Madhya, Uttar and Dakshin Gujarat companies respectively (assuming cost to serve grid power at INR 5/kWh) ; in contrast, on grid connected tubewells on those feeders, they incurred subsidy of INR 881, INR 1551, INR 1330 and INR 1228 per HP respectively (taking subsidy on cost to serve grid power as INR 4/kWh).

capital for solarization. However, the model does not provide for any specific incentive for farmers to conserve energy and water since they continue to receive free daytime power for irrigation.

Even before the impacts of these and other SIP promotion models had become clear, the Government of India announced the PM-KUSUM[8] scheme, a national programme for agricultural solarization with three components (Hindu Business Online, 2019) at a proposed cost of USD 6 billion:

Component A: Establishment of 10 000 mW of decentralized ground-mounted, grid-connected renewable power plants of individual plant size up to 2 mW (after the Maharashtra model).
Component B: Installation of 1.75 million standalone solar-powered agricultural pumps of with capacity up to 7.5 HP (for water-abundant, energy-starved districts).
Component C: Solarization of one million grid-connected solar-powered agricultural pumps with capacity up to 7.5 HP (after the SKY model).

The Government of India's latest budget, announced on February 2020, increased the target under Component B to 2 million and under Component C to 1.5 million SIPs.

SKY and KUSUM (Component C) are bold schemes that aim to address India's pernicious WEF nexus, which has resulted in high costs for electricity utilities, depleted aquifers, a high carbon footprint irrigation economy and unsustainable agriculture. While there are many reasons that the schemes received policy traction, at the same time, there are high political costs to measuring and charging for grid power supplied to farmers. On the other hand, there may be huge political dividends to be reaped from measuring and paying for solar energy that farmers grow on their fields and sell to the grid.

Governance lessons

1. Gujarat's search for innovative indirect governance instruments for addressing key trade-offs from WEF nexus involved a learning process that began with Jyotigram.
2. Nexus refers to a class of multisectoral anomalies that can only be resolved together. The Maharashtra model of tail-end solar plants to solarize farm feeders is *not* a nexus solution because it assumes that the energy solution must be implemented separately and any water sector anomalies that result should be resolved through an independent water solution. This has been tried before and has not worked in practice. SKY is a classic nexus solution.
3. Whether SKY will produce expected behavioural changes will depend upon its design, particularly the economic incentives and disincentives that are included in the scheme.
4. Indirect nexus levers are benign in terms of political costs. Designed correctly, they can deliver political dividends that invite leaders to put their weight behind them.

[8] Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (Prime Minister's Farmer Energy Security and Development Initiative)

Synthesis and conclusions

The nexus ideal

Water governance includes a role for the state in addressing water scarcity problems. A state can act through: public provision/proscription, promotion/regulation and incentives/disincentives, which involves making policy choices, adopting and enforcing laws, and innovating institutional arrangements.

Both IWRM and the nexus approach provide a normative framework in which the state can act to produce society-wide rather than sectoral benefits. The nexus approach enjoins us to heed the interactions between water, energy and food security for "increasing efficiency, reducing trade-offs, building synergies and improving governance across sectors" (Hoff, 2011, p. 4). The nexus ideal is a water governance regime that achieves a balance between food security, water productivity, energy efficiency, resource sustainability, ecosystem health and societal well-being.

In this review paper, we have explored seven examples of groundwater governance regimes that strayed from this ideal and, for a time, pursued the sectoral objective of expanding irrigation and food production. In the process, they all digressed from the holistic nexus optima, and struggled to inch towards the nexus ideal, with varying degree of success. Table 2 summarizes the hydro-geological setting, the hierarchy of national policy priorities that led to irrigation-driven groundwater overabstraction, and its direct and indirect socioecological impacts, which spanned some 100 million hectares of groundwater-stressed landscape in selected geographies. There is growing recognition of the environmental risks of such a scenario and new groundwater governance measures have been instituted to restore the balance. The measures and their impacts are summarized in Table 3.

Table 2. Drivers and Impacts of Rapid Expansion of Tubewell Irrigation on groundwater socioecology

#	Geography	Hydro-geology	Driver of groundwater boom	Hierarchy of policy priorities	Environmental impacts	Size of the drgraded landscape	Fate of pre-existing irrigation regimes
1	Iran: 1960-2020	Semi-arid, alluvial	95% subsidy on energy and tubewells; guaranteed grain purchaset at lucrative price	Food self-sufficiency; grow irrigation under *jihad* agriculture	Secular groundwater depletion; water quality deterioration; secondary salinization	15 million Ha	30000 qanats in dereliction
2	Saudi Arabia: 1982-2000	Arid alluvial	95% subsidy on energy and tubewells; guaranteed grain purchaset at lucrative price	National food self-sufficiency; resettle Beduin small farmers	Secular depletion of fossil groundwater; quality deterioration; secondary salinity	1.8 million ha	Numerous oases and wadis desciccated
3	Mexico: 1950-2020	Semi-arid, alluvial & carst	Subsidy on energy; high subsidy on night power supply	Support high value export agriculture; support ejidatarios	abstractions exceeded long term recharge in most aquifers; extensive land subsidence	12- 15 million ha	Decline of Chinampa system of irrigation developed by Aztecs
4	North China plains: 1960-2014	Semi-arid, alluvial	Population pressure on farmland; moderate equipment subsidy	Food production and livelihoods of small family farmers	Extreme groundwater depletion; drying uo of surface flows; quality deterioration; low flows in Yellow river and tributaries	22- 25 million ha	Ground water replaced surface water increasingly diverted for industrial use
5	Barind, Bangladesh 1985-2020	Humid, hardrock	Slow and unequitable groundwater development	Equitable irrigation access; integrated area development	Agrarian poverty; Patchy irrigation availability despite high rainfall; no summer paddy crop;	2.5- 3 million ha	Old canals and ponds fell in disuse
6	Western India 1960-2006	Semi-arid, alluvial-hardrock	Energy subsidy; moderate equipment subsidy;	Improve farmer livelihoods; accelerate agricultural growth	Secular groundwater ddepletion over large swathes; increased fluoride and salinity in groundwater; drying of surface streams and rivers	45- 55 million ha	0.5 million irrigation tanks derelict; irrigation canals turned percolation canals

Table 3. Towards the nexus ideal: groundwater governance strategies and their impacts

#	Geography	Key Reforms initiated in Groundwater Governance since 1990	Eco-system Impact	Social Impact
1	Iran: 1960-2020	[1] Water abstraction quota's issued to each tubewell owner; [2] smart meters begun to get installed on tubewells to monitor water abstraction against quota; [3] penalty tariff collected for exceeding quotas; [4] campaign against illegal rigs and tubewells with special police; [5] subsidy for drip and sprinkler irrigation; [6] wheat purchase prices reduced	+	Resistance among farmers; new quota rules at variance with qanat allocation rules; enforcement capacity poor; qanats left in disuse and public irrigation performance poor
2	Saudi Arabia: 1982-2000	[1] government wheat purchase phased out and imports began to meet national requirement; [2] irrigation subsidies phased out; [3] new laws and decrees passed but enforcement poor; [3] massive investments in desalination	++	Wheat irrigation declined ; but groundwater abstraction fell less than proportionately; enforcement poor. Poor beduins left out, while farming companies gained.
3	Mexico: 1950-2020	[1] Aquifer Committees (COTAS) organised; [2] groundwater concessions issued; [3] markets in concessions catalysed; [4] ban on new tubewells announced; [5] electricity subsidies only on authorised tubewells. Overall, groundwater governance remained half-hearted and enforcement weak.	+	COTAs failed produce behaviour change; repeated presidential amnesty on ban on illegal wells made laws toothless; subsidy on night power supply deepened perverse behaviour. Ejidatario's left worse off.
4	Shiyang basin, China: 1960-2014	[1] 3300 tubewells closed; [2] irrigation reduced by over 6,50,000 ha; [3] household level water permits strictly enforced using smart meters; [4] progressive penalty for exceeding quota and bonus for using less than quota; [5] 874 WUAs helped village level enforcement; [6] aggressive promotion ofmicro-irrigation and high value crops	+++++	Shiyang Bureau achieved reduction in groundwater draft; but agrarian livelihoods were hit hard; many farmers quit farming; many others found off-farm livelihoods. May prove unreplicable elsewhere
5	Barind, Bangladesh 1985-2020	[1] Resource governance started with development and access; [b] demand-driven groundwater development; [c] tubewells constructed and managed centrally; [d]full-cost pricing and recovery; [e] groundwater monitoring; [f] demand and supply side interventions in stressed areas; [g] affofrestation, water conservation and recharge, conjunctive management of surface and groundwater	+++++	Barind model was closest to the 'nexus ideal'; it provided equitable irrigation, protected aquifers, invested in eco-system services and proved financially viable. Model for regions in early stages of irrigation development. More, BMDA's success may be hard to replicate.
6	Gujarat, *Jyotigram 2003-6*	[1] Community driven groundwater recharge movement helped improve groundwater capture and storage during 1990-2015; [2] agricultural feeders separated from rural feeders; [3] farmer provide 8 hours of high quality power ration during day and night in alternate weeks; [4] New scheme (SKY) replaces grid connected tubewells by solar pumps with 25 year guarantee for purchase of solar power at a remunerative price	++++	Improved groundwater regime, accelerated agricultural growth, improved livelihoods. Dissatisfaction with reduced power ration was overcome by improved power quality. Non-farm rural electricity consumers happy with improved quality of life. New solar program with power buy-back guarantee met with farmer enthusiasm.

The results have been variable. In Iran (Islamic Republic of), Saudi Arabia and Mexico, reforms produced modest sustainability outcomes. In Shiyang Basin (China), the Barind project (Bangladesh) and Gujarat (Western India), there are indications that governance reforms are headed in the right direction to deliver holistic nexus outcomes. A strong enforcement capacity, reaching down to the village level, was the hallmark of the Shiyang Basin success. The BMDA's focus on the integrated governance of water and land from the start of irrigation development was the key reason for the Barind project's success. In Gujarat, governance reforms had to contend with a long history of farmer stakes in perpetuating energy subsidies. Policymakers had to find indirect modes of intervening that would be easy to implement without adverse political consequences. As it turned out, the reform implemented in Gujarat helped the state move towards the nexus ideal. The strategy has been replicated in several states of India, albeit with variable outcomes.

Context, contingencies and constituencies. To bridge the chasm between nexus thinking and conventional groundwater governance, we need to pay attention to the forces that shape the latter. Our review suggests that three forces operate in each geography: context, contingencies and constituencies. The social, political and economic context of a country or province are key determinants of governance choices. India prioritizes farming livelihoods because 60 percent of its population depends on farming, as compared to Saudi Arabia (8 percent) or Iran (Islamic Republic of) (18 percent). Similarly, water policy interventions are shaped by contingencies facing governments at that time. Iran (Islamic Republic of) and Saudi Arabia would be less compelled to chase food self-sufficiency if they were confident about importing food at will. Finally, governance affects different constituencies differently. In Mexico and Iran (Islamic Republic of), political leaders repeatedly granted amnesty over illegal wells because their owners constituted a powerful constituency. Even where the beneficiaries of a policy are a tiny section of the population, they can still be a powerful political interest group, as in Saudi Arabia and Mexico. Understanding context, contingencies and constituencies facing national and provincial authorities is critical for moving water governance away from silo thinking towards a holistic perspective.

Hierarchy of priorities. Nexus advocacy must recognize the different hierarchies of the national priorities within which water governance choices are made. These change over time. In Iran (Islamic Republic of) in recent years, in Saudi Arabia during the 1980s and India during the 1960s, national food self-sufficiency was the primary objective. Saudi Arabia has now consciously chosen to import food and save its water. Iran (Islamic Republic of) continues to prioritize food security (Lyddon, 2019), and India, which still has high levels of food insecurity and malnutrition considers protecting farm incomes and livelihoods as a higher priority than other national objectives, as is revealed by its water governance choices. Shiyang Basin Authority's success in reducing groundwater overdraft is impressive, but China may hesitate in scaling it out nationally if doing so threatens the country's grain production.

Institutional capacity. Building deep and broad-based institutional capacities – among community and civil society organizations, citizen-centric bureaucracies and customer-oriented service providers – may be the most powerful means to achieve the nexus optima in emerging economies. Even when policymakers and leaders are ready to support WEF nexus outcomes, as they did in Saudi Arabia, Iran (Islamic Republic of) and India, success may take time due to limited institutional capacity to make and enforce rules and to deal with resistance from farmers. The required monitoring and enforcement capacity is determined by the number of groundwater users rather than the volume of groundwater extracted. For example, Mexico has difficulties in monitoring and managing its 100 000 tubewell owners; in India, monitoring groundwater extractions by its 22 million tiny scattered tubewell owners is close to impossible. It is therefore not surprising that numerous laws and decrees by national and provincial governments in India suffer from lack of implementation and enforcement. It is also notable that to implement an indirect governance intervention, Gujarat has not worked with water administration, which is dominated by engineers whose skills are in building infrastructure, but implemented the entire reform through electricity companies and community organizations instead.

Inter-agency strategic coherence. A key aspect of capacity building is creating strategic coherence among the different agencies dealing with water, energy, food, agriculture, environment. In countries like Iran (Islamic Republic of), Mexico and India, these agencies often pursue contradictory objectives and work at cross-purposes. Agriculture agencies promote expansion in groundwater irrigation; water agencies' primary concern are dams and canals; and energy agencies strive to mitigate subsidy burdens. It seldom happens that these come together to see water, energy and food as components of a larger ecosystem. Such a holistic perspective is generally only offered by the top political or administrative leadership. In Shiyang Basin, the directive to create a groundwater-saving agricultural economy came from Beijing, just as in Saudi Arabia, the decision to phase out wheat export came from the top political leadership. Meanwhile, in Iran (Islamic Republic of), the Iranian Jihad Agriculture Agency pursues expansion in wheat irrigation by tubewells, while the Iranian Ministry of Energy has begun to control energy and groundwater use in irrigation.

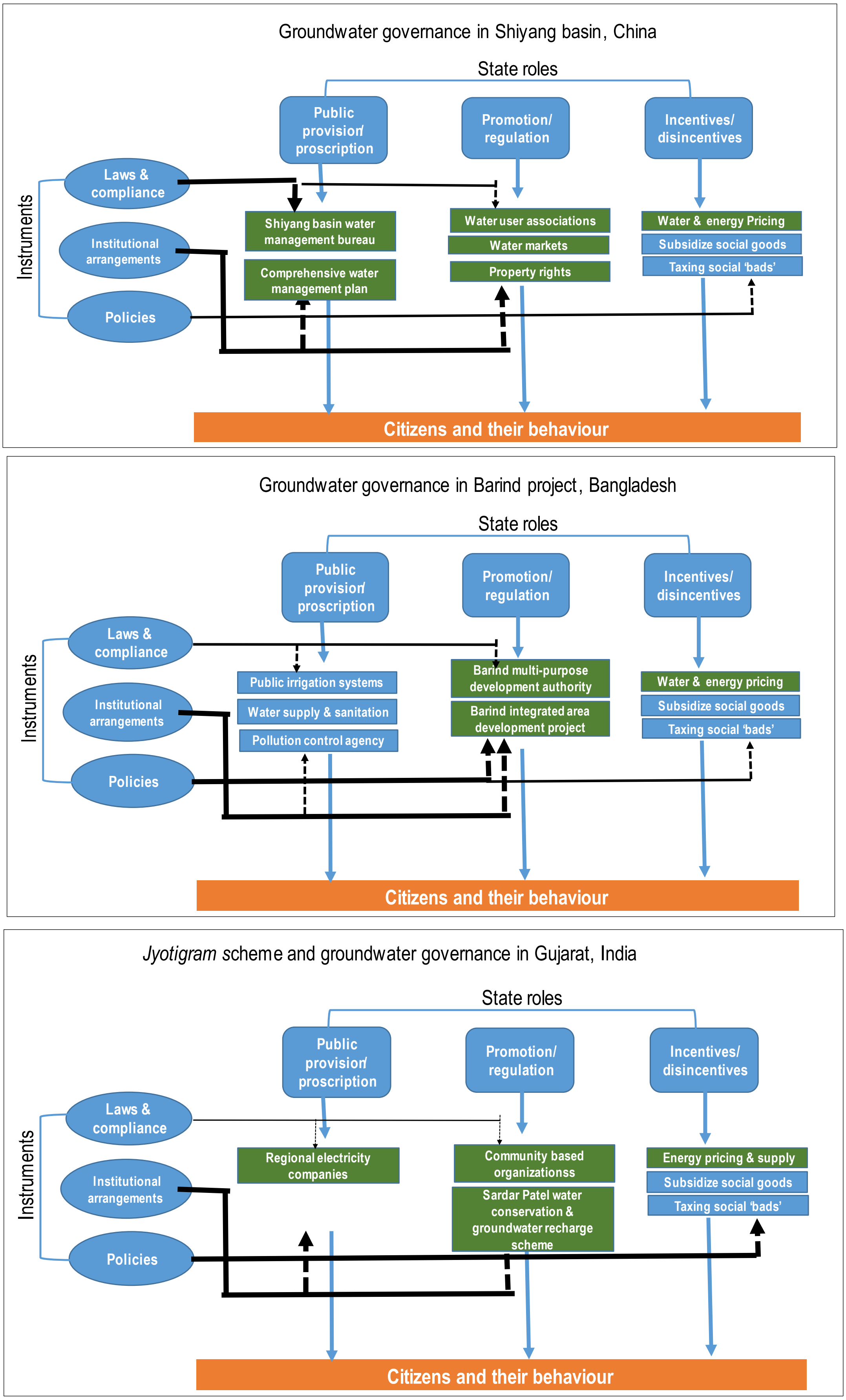
Symptomatic versus holistic interventions. Experience with groundwater governance has shown that policy interventions may change the symptoms but leave the problem unresolved. This is because intervention design ignores the Jevons paradox,[9] and often assumes that farmers will not push back to protect their incomes. Saudi Arabia's purchase of wheat at lucrative prices started its groundwater boom. When government purchases stopped, wheat production fell drastically but water withdrawals did not, because farmers took to alfalfa cultivation, which uses four times more groundwater than wheat. Metering tubewells and penalizing excess water use in Iran (Islamic Republic of) produced similar results: farmers grew less wheat but began to plant water-loving fruit trees, which guzzle more water as they grow.

Every innovative solution invariably contains the seeds of future trouble if it only addresses the symptoms and not the problem. The Punjab and Haryana states of northwestern India experienced a decline in groundwater levels, thanks to the vast areas of rice and wheat irrigation that were sustained by energy subsidies and state purchases of grain at attractive prices. During the early 2000s, scientists found that much of groundwater use in paddy irrigation came from farmers using tubewells to water nurseries in the very hot temperatures of May, weeks before the monsoon rains. The government passed a law banning rice transplantation before 10 June, which led to a reduction in groundwater withdrawals. However, the delayed planting of rice led to delays in harvesting, with little time left for farmers to prepare land for sowing the winter wheat crop. To empty their fields quickly, farmers began to set fire to the rice fields to get rid of paddy stubble. Meteorological and cold winter conditions prevented a quick dispersal of the smoke these fires produced. This created a massive winter air pollution problem that seriously worsened air quality in Delhi and the entire Indo-Gangetic plain (Vasdev, 2019). Now the issue is whether north India is better off depleting groundwater or polluting its air.

Alternative governance pathways. Barind in Bangladesh, Shiyang Basin in China and Gujarat in western India are three places where we can find notable movement towards the nexus ideal. However, the governance route followed in each case has been different, as shown in Figure 4. China created the Shiyang Basin Water Management Bureau (SBWMB) as a parastatal special purpose vehicle (SPV). Likewise, Bangladesh created BMDA as a parastatal SPV. These agencies orchestrated a turnaround in the groundwater situation. In Gujarat, regional energy companies – rather than water administration, were chosen to rewire the rural grid and manage rationed farm power supply – while community-based organizations were funded to undertake a decentralized groundwater recharge movement. The contingency theory of management can readily be applied to water governance: there is no best way to execute governance reform. The optimal course of action is contingent upon the internal and external situation facing decision-makers in a given setting.

[9] The Jevons Paradox states that, in the long term, an increase in efficiency in resource use will generate an increase in resource consumption rather than a decrease.

Figure 4. Alternative pathways to holistic water governance



Source: author's own elaboration

We conclude this paper with a quote from John Briscoe's speech delivered when he received the World Water Prize in early 2014:

> Every water solution is a local solution. Moreover, every solution is provisional and contains the seed of a future problem; it works for a time and there is a constant challenge and response cycle. The spiral-like reflexive relationship between water and economic growth [implies that] improved water management promotes growth, and economic growth creates opportunities for new kinds of water management interventions, which are hard to implement when income levels are low…In poor countries, [we must] give primacy to creating appropriate water infrastructure and building capacity for its sustainable management as the first step to improving management of the water economy… [While] transparency, equity, good governance, and participation have high *intrinsic* value, they have doubtful *instrumental* value, in the sense that these are neither necessary nor sufficient for improving the working of a water economy or for removing poverty (Briscoe, 2014).

Briscoe advocated a pragmatic but principled approach to water governance. Pragmatic and principled – rather than formulaic – were the groundwater governance approaches that helped Shiyang, Barind and Gujarat to move toward the nexus ideal. Had he been alive, Briscoe would have argued for the nexus approach as conceptual backdrop against which national and local authorities might design pragmatic and principled water governance consistent with their respective contexts, contingencies and constituencies.

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This review paper focuses on the WEF nexus in action. We compare the nexus in several water-stressed areas of the world including the Islamic Republic of Iran, Saudi Arabia, Mexico, China, Bangladesh and Gujarat (India), with additional evidence drawn from other places such as Morocco and Punjab-Haryana. We synthesize these case studies to examine the actual state of play in different locations and tease out practical lessons for mainstreaming nexus thinking in water policy and governance. The key conclusion is that specific contexts, contingencies and constituencies drive national and sub-national policies. Directing the outcomes towards the optimal nexus depends on the nature of the state, investment in institution building and, above all, ingenuity in policy design and implementation to overcome resistance to change and strengthen political capital for the leaders who back such policies.

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