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Featured Article

Sustainable Groundwater Management in India Needs a Water-Energy-Food Nexus Approach

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Abstract *Groundwater depletion in India is a result of water, energy, and food policies that have given rise to a nexus where growth in agriculture has been supported by unsustainable trends in water and energy use. This nexus emanates from India's policy of providing affordable calories to its large population. This requires that input prices are kept low, leading to perverse incentives that encourage groundwater overexploitation. The paper argues that solutions to India's groundwater problems need to be embedded within the current context of its water-energy-food nexus. Examples are provided of changes underway in some water-energy-food policies that may halt further groundwater depletion.*

Key words: groundwater, electricity policies, food policies, water-energy-food nexus, Green Revolution, India.

JEL codes: Q4, Q15, Q18, Q25.

Introduction

In 2009, NASA scientists published a paper using Gravity Recovery and Climate Experiment satellite data (GRACE) showing a massive area of groundwater depletion in the Indian states of Rajasthan, Punjab, and Haryana between 2002, when the GRACE satellite was launched, and 2008 (Rodell, Velicogna, and Famiglietti 2009). This hotspot of groundwater depletion was one of the first terrestrial water storage trends detected outside the polar regions. It did not go unnoticed in the public discourse that a hotspot of groundwater depletion coincided with the Indian states of Punjab and Haryana, the states which reaped the earliest and most persistent benefits of the Green Revolution (Pingali, Mittra, and Rahman 2017), aided by highly subsidized electricity and lucrative government-declared support prices for crops like paddy. Barely four decades earlier, Norman Borlaug, the father of the Green Revolution, was awarded the Nobel Peace Prize in 1970 for his contribution to the eradication of world hunger through phenomenal increases in productivity of cereal crops like wheat and rice (Borlaug 1971). At the same time, there were massive national and international investments in research and development to help spread the Green Revolution (Lele and Goldsmith 1999). Food production in India increased rapidly as a result (figure 1), and rural poverty declined in those states that benefited (Pingali 2012). Volume and pace of groundwater extraction also increased rapidly in the 1970s. Intensive groundwater use was a result of a subsidized electricity policy, easy availability of credit for constructing groundwater wells and buying pumps, and food procurement policies that guaranteed procurement of rice and wheat crops. These policies were introduced to encourage farmers to adopt Green Revolution technologies in its initial phases but have remained unchanged over decades, leading to groundwater depletion. There is now a widespread consensus that groundwater depletion poses a serious threat to future food security in the region and climate change further exacerbates these problems (Asoka et al. 2017; Dalin et al. 2017).

In this paper, I trace the link between the current state of groundwater depletion and the water, energy, and food (WEF) policies put in place in the 1960s and 1970s. India is the world's largest user of groundwater, with an annual draft of 250 km^3 (Aeschbach-Hertig and Gleeson 2012). Since the 1970s, there has been a rapid increase in the area under groundwater irrigation (figure 2). There are roughly 20 million irrigation wells in India (GOI 2017), the highest number anywhere in the world. Groundwater-led irrigation was instrumental in the success of the Green Revolution in India, mostly because of its accessibility and reliability as compared to canal irrigation (Shah 1993).

I further argue that India's WEF nexus emanates from policies dating back to the 1960s and 1970s, which were brought in to support the mission for food self-sufficiency (Pingali et al. 2017) and providing affordable food for its urban nonfood-growing population (Howes and Jha 1994; Mooij 1998). This required that input prices be kept low, including prices for electricity, which led to perverse incentives for groundwater overpumping. As a corollary, I argue that since groundwater depletion in parts of India is a result of

Figure 1 Area (million hectares) and production of food grains (million metric tons) and % area irrigated under cereals [Color figure can be viewed at wileyonlinelibrary.com]

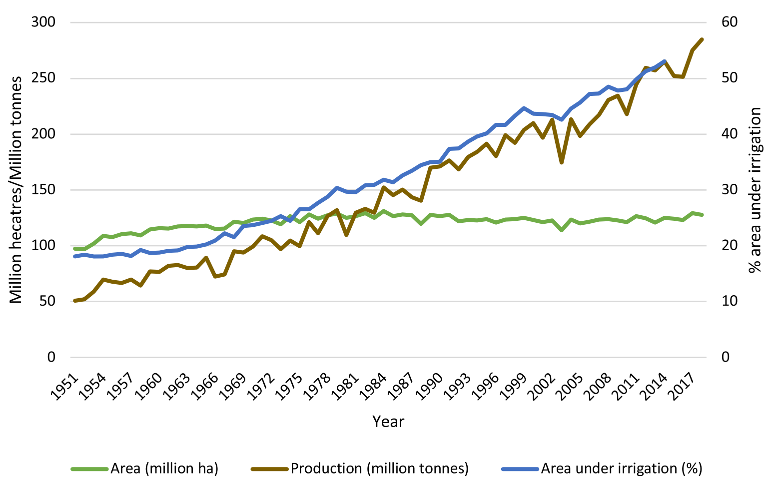
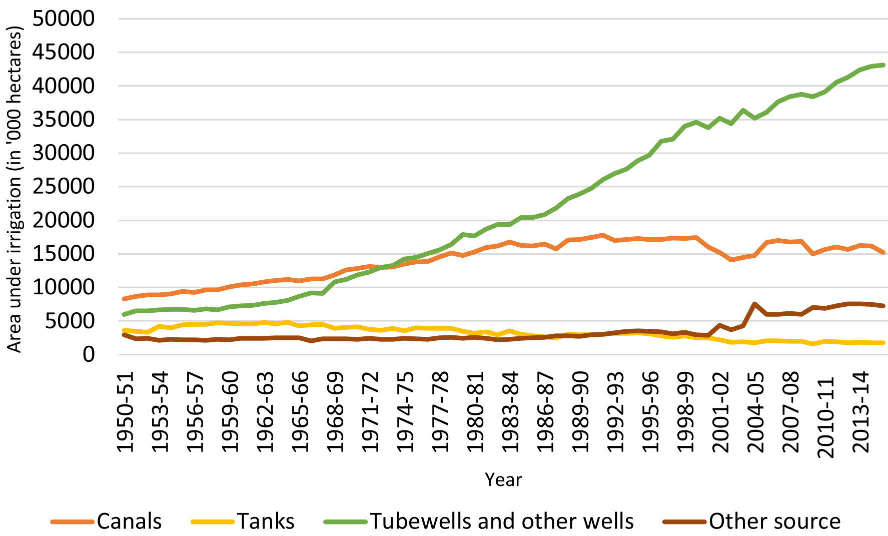


Figure 2 Area under different sources of irrigation 1950–1951 to 2014–2015 (thousand hectares) [Color figure can be viewed at wileyonlinelibrary.com]



interlinked food and energy policies, solutions to India's groundwater problems also need to be embedded in its unique WEF nexus. The paper goes on to discuss solutions emanating from WEF sectors that can halt further groundwater depletion.

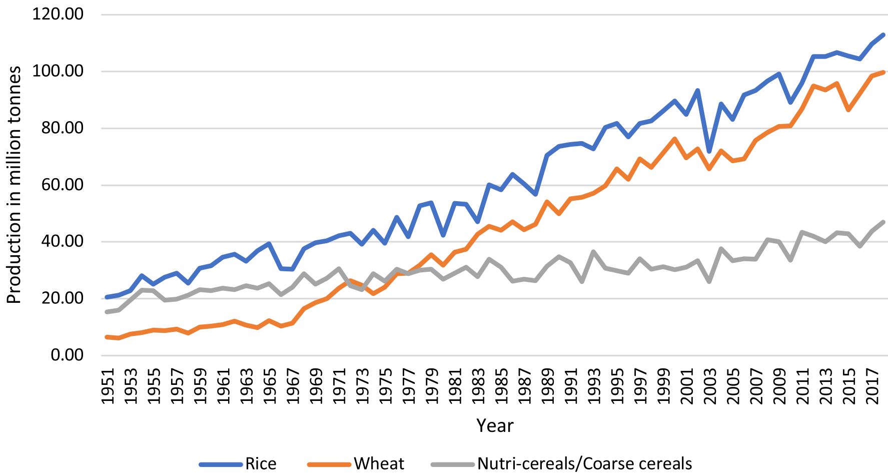
WEF Policies in Support of the Green Revolution in India

Independent India's initial thrust toward industrialization and a host of other factors, including weather-induced vagaries, led to a massive food crisis in the mid-1960s. Food assistance from the United States government's Public Law 480 food aid program was perceived to threaten India's long-term sovereign interests without meeting the short-term interest of food price stability (Pingali et al. 2017). Green Revolution technologies were introduced in India under the sociopolitical conditions of the 1960s. These technologies consisted of high-yielding seeds, chemical fertilizers, and irrigation. From food deficits in the 1960s, India became food self-sufficient in the 1970s. Total food grain production in India went from 81.6 million metric tonnes in the triennium ending (TE) 1960–1963 to 270.3 million metric tonnes during TE 2015–2018. The area under irrigation also went up from 19% of net cultivated area (NCA) in TE 1960–1962 to almost 52% of NCA in the year ending 2017–2018 (figure 1). Of India's 67.3 million hectares of net irrigated area, 43.1 million hectares were irrigated by groundwater in 2015–16 (GOI Ministry of Agriculture and Farmers Welfare 2020). The area under groundwater irrigation expanded rapidly from the mid-1970s and was thought to be instrumental in the success of the Green Revolution in India (figure 2). In the sections that follow, I discuss WEF policies that were brought in to support the Green Revolution.

Food Policies: Minimum Support Price and Public Distribution System

The need to achieve national food self-sufficiency and provide food at affordable and stable prices were the two main policy objectives that

Figure 3 Production (in million metric tons) of rice, wheat, and nutri-cereals, 1950–1951 to 2017–2018 (GOI 2018) [Color figure can be viewed at wileyonlinelibrary.com]



underpinned the Green Revolution in India. Central to its success were the twin policies of a minimum support price (MSP) for wheat and paddy for farmers and a policy for distribution of subsidized food grains through the public distribution system (PDS) for consumers (Pingali et al. 2017). Both paddy and wheat are water-intensive crops and are nutritionally poor compared to coarse cereals (now called nutri-cereals) like sorghum and millets. Figure 3 shows that by the mid-1970s, production of wheat overtook that of nutri-cereals, and between 1950 to 2018, production of wheat and rice grew at rates several times higher than that of nutri-cereals. The MSP for rice and wheat encouraged their cultivation over nutri-cereals as rice and wheat fetched relatively more assured incomes.

MSP and PDS policies created strong farmer lobbies, especially Punjab and Haryana, which had reaped the initial benefits of the Green Revolution. These lobbies, mostly comprised of midsized farmers, exerted considerable political influence on setting MSP prices for crops like paddy, wheat, and sugarcane. This wave of farmer politics came to be known as the "new agrarian movement," where farmers unionized to bargain for higher MSPs and input subsidies (Rudolph and Rudolph 1987). The imperative to keep food prices low for urban consumers also meant that input subsidies had to continue so the cost of production for farmers could be kept low. Studies found that the availability of subsidized grains (rice and wheat) through PDS led to changes in the composition of traditional diets in many parts of India, away from the more nutritious nutri-cereals to less nutritious wheat and rice (Drèze and Khera 2017). India's food policy, set in an era of food shortages and high food-price volatility, may be an obstacle to reforms in response to emerging challenges such as groundwater depletion, and high incidence of malnutrition, by providing perverse incentives to farmers to continue growing crops which are both water intensive and less nutritious.

Electricity Policies: Subsidized Electricity Tariffs to Support Groundwater Pumping

Rural electrification, especially electrification of pump sets, became an important policy priority in the late 1960s. This shift happened in response to a series of droughts in India in the early to mid-1960s and followed the discourse on national food self-sufficiency through small-scale groundwater irrigation. On the recommendation of the Reserve Bank of India, the Rural Electrification Corporation Limited was set up in 1969 to promote pump electrification. By the early 1970s, there were more than a million wells with electric pumps in the country (Palit and Bandyopadhyay 2017). Easy availability of credit, sharp declines in well drilling costs, and the availability of Green Revolution technologies that ensured high returns on irrigation led to massive private investments in groundwater wells (Shah 1993).

Electricity tariff policies played an important role in incentivizing groundwater pumping. Initially, almost all groundwater wells were metered, and farmers were billed for their actual electricity use. However, the cost of metering and billing, coupled with problems arising from collusion among farmers and meter readers, made collecting payments difficult. Most state electricity boards (SEBs) shifted to flat tariffs in the 1970s (Shah, Giordano, and Mukherji 2012). Flat tariffs meant that farmers received a fixed electricity bill irrespective of actual hours of pumping. Flat tariffs created a political economy of its own, with strong political demands by farmers to keep flat tariffs perpetually low.

On the positive side, flat tariffs, especially when they were nontrivial, provided an incentive to pump owners to sell irrigation services to small and marginal farmers who did not own wells. Competitive water markets emerged in many states (Mukherji 2007; Sidhu, Kandlikar, and Ramankutty 2020; Shah 1993) and benefited small and marginal farmers. According to an estimate based on data from the National Sample Survey Office, informal water markets served up to 20 million hectares, or one third of India's irrigated area (Mukherji 2008). On the negative side, because flat tariffs were hardly ever revised to reflect the real cost of electricity supply, it led to massive losses for the SEBs. The financial distress of the SEBs led to poor upkeep of rural electricity infrastructure, and farmers received poor quality and unreliable electricity supply (Shah, Giordano, and Mukherji 2012).

This vicious cycle of poor financial conditions of SEBs and poor quality of service to consumers led to the electricity reforms of 2003 (Dubash and Rao 2008). Electricity reforms of 2003 brought about some fundamental changes in the way the electricity sector in India was managed. First, it led to an unbundling of SEBs. Generation, transmission, and distribution functions were unbundled and formed into separate companies. State Electricity Regulatory Commissions (SERCs) were formed in every state. SERCs were tasked with determining tariffs, among other things. Most SERCs then put forward stricter methodologies for calculating agricultural electricity consumption, which led to more realistic estimates of consumption, although still not accurate due to the lack of metering. This put pressure on newly unbundled utilities to improve overall service quality, including agricultural electricity supply (Dubash and Rao 2008). However, these reforms failed to make much headway on the issue of electricity tariffs. Few states were actually able to introduce metering of agricultural connections, given the strong political lobby that opposed any metering or increase in tariffs (Mukherji 2006). States did manage to introduce other electricity-related measures that had the potential to impact groundwater pumping. These measures are discussed in a later section.

Water Policies: Public Investment Failure in Canals and Public Tubewells Leading to Private Investments in Groundwater

Figure 2 shows sources of irrigation in India. Broadly, before the 1970s, surface water in the form of canals and tanks irrigated most land in India. Since the mid-1970s and coinciding with the Green Revolution, the area under groundwater irrigation started growing faster than all other sources of irrigation. Much of this groundwater irrigation was in the form of private investments by farmers.

However, unlike the food and electricity sectors where explicit policies were framed in support of Green Revolution technologies, in the case of private groundwater led irrigation expansion, it was the failure of public tubewell programs that provided the impetus to private investments in groundwater (Kolavalli and Shah 1993). Groundwater ownership is dictated by Common Law Principles inherited from British colonial law (Cullet 2014). In practical terms, it means that landowners have *de facto* ownership of the groundwater below their land. While India has had a long history of open well irrigation using manual or animal power, mechanized groundwater irrigation was introduced in the 1950s and 1960s through state public tubewell programs (Shah 2009). All major Indian states invested in public tubewells, but most of these programs failed because of complex technology and bureaucratic procedures (Mukherji and Kishore 2003). However, public tubewells did demonstrate that groundwater could be tapped effectively for irrigation. With the advent of the Green Revolution and lower drilling costs, farmers found it profitable to invest in groundwater irrigation wells (Shah 1993). The number of groundwater irrigation structures went from 6.2 million in 1986–1987 to 20.5 million in 2013–2014 (GOI 1987, 2017).

At the same time, bureaucratic and design failures limited the expansion of canal irrigation (figure 2). Canals were designed in the pre-Green Revolution era for meeting the irrigation demands of a maximum of one crop a year. However, small landholdings and the imperative to earn a living from these small plots necessitated that farmers grow two to three irrigated crops in a year. Canals could not cope with such intensive demand and farmers increased their reliance on groundwater as figure 2 shows.

The WEF Nexus in India and its Impacts on Agriculture, Electricity, and Groundwater Sectors

The result of these policies was the creation of a unique WEF nexus, where growth in agricultural production was supported by unsustainable trends in the groundwater and energy sectors. In this section, I describe some of the ramifications of Green Revolution-led agricultural growth in the groundwater and energy sectors.

By 2015–2016, roughly 64% of India's net irrigated land of 67.3 million hectares was under groundwater irrigation (GOI Ministry of Agriculture and Farmers Welfare 2020). Studies show that agricultural production in India would have been much lower without subsidized groundwater irrigation (Smilovic, Gleeson, and Siebert 2015). Initially, vibrant water markets encouraged by flat tariffs extended the benefits of groundwater irrigation to poor water buyers (Shah 1993). However, as groundwater was depleted and the power supply reduced, these markets started dwindling (Mukherji 2008). Management of canal and tank irrigation command areas deteriorated because farmers preferred to install their own tubewells (Shah 2009). Several states such as Punjab, Andhra Pradesh, Karnataka, Haryana, Gujarat, Rajasthan, Madhya Pradesh, Maharashtra, and Tamil Nadu overexploited their groundwater resources (figure 4). Failure of wells in the hard-rock peninsular region has negatively impacted farmers' ability to adapt to climate change (Blakeslee, Fishman, and Srinivasan 2020).

After the Green Revolution, agricultural electricity consumption went up rapidly (GOI Ministry of Statistics and Programme Implementation 2020; figure 5). Around the turn of the millennium, the World Bank estimated farm power subsidies to be around "USD 6 billion a year, about 25 percent of India's fiscal deficit, twice the annual public spending on health or rural development, and two and a half times the yearly expenditure on irrigation" (Monari 2002). Removal of meters on tubewells undermined energy accounting in power utilities and impaired their internal accountability systems (Shah, Giordano, and Mukherji 2012). The SEBs were in financial distress as a result of losses from agricultural electricity supply.

Figure 4 Categorization of administrative blocks in India according to groundwater status (as of 31 March 2017) (CGWB 2017) [Color figure can be viewed at wileyonlinelibrary.com]

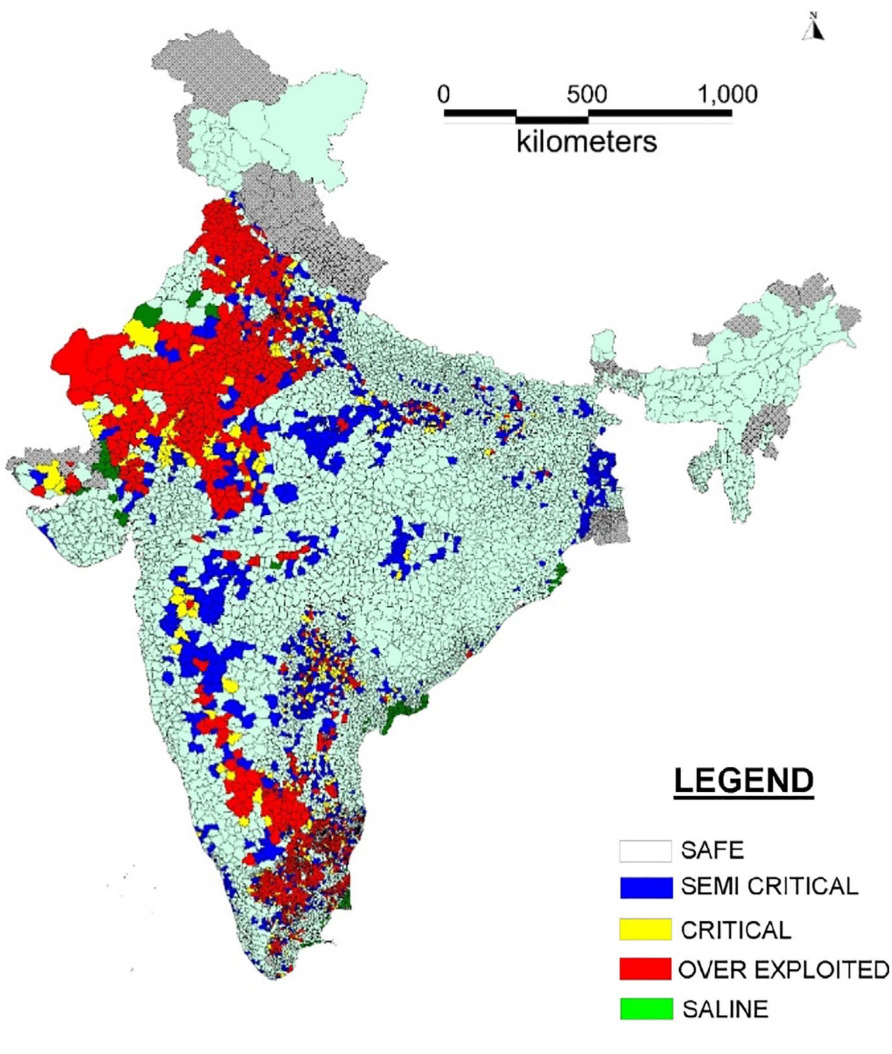
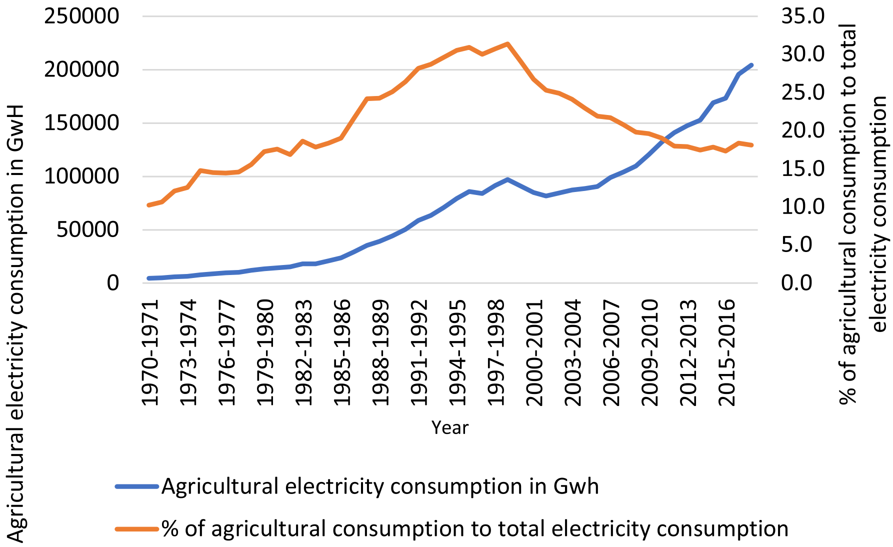


Figure 5 Growth in agricultural electricity consumption in India, 1970–1971 to 2017–2018 (GOI 2020) [Color figure can be viewed at wileyonlinelibrary.com]



Examples of WEF Nexus Solutions that Can Potentially Reduce Groundwater Use

So far, I have argued the current unsustainable groundwater trend in large parts of India is a direct result of the food and electricity policies dating back to the 1960s and 1970s. In the following sections, I present some of the attempts at policy reforms in the food, groundwater, and energy sectors that have either affected groundwater use or could affect its use in the future.

Policy Changes Related to Agriculture, Food, and Nutrition

Two policy thrusts are particularly relevant from a water-use point of view. First is the inclusion of nutritious but low water-consuming food grains (Notaro et al. 2017), like nutri-cereals in some of the major public nutrition schemes such as midday meals in schools and the Integrated Child Development Scheme (ICDS; Drèze and Khera 2017). India's poor performance in child nutrition outcomes (Deaton and Drèze 2009; Das, Sharma, and Babu 2018) has led to a renewed focus on nutrition in social security schemes (Drèze and Khera 2017). Recent policies such as the National Food Security Act of 2013 have included nutri-cereals as part of targeted PDS. There are also plans to serve nutri-cereals in schools as part of midday meals and at *angaanwadis* (child care nurseries) as part of the ICDS in some states like Odisha (IANS 2019). There is some evidence to show that incorporating nutri-cereals in midday meals leads to better nutritional and cognitive outcomes for children (Anitha et al. 2019). Given the widespread concern about India's nutrition deficit, more states are likely to promote nutri-cereals in their nutrition programs. This may incentivize farmers to grow less water-intensive crops. Studies have shown that it is possible to reduce irrigation demand (Davis et al. 2018), and agricultural emissions (Rao et al. 2018), while improving the production of calories, protein, iron, and zinc by replacing rice with other cereal crops like maize, finger millet, pearl millet, or sorghum.

Second, is the renewed thrust on the Green Revolution in eastern India. It is argued that eastern India, with its abundant water resources, could become the rice bowl of India, while water-scarce northwestern Indian states could grow less water-intensive crops (Mukherji, Shah, and Banerjee 2012). The traditional argument that eastern India is less suited for Green Revolution technologies due to its humid agro-ecological conditions has been put to rest by the success of the Green Revolution in Bangladesh, which shares a similar agro-ecology with eastern India (Headey and Hoddinott 2016). It is now realized there are a host of other impediments in eastern India. These include a lack of affordable access to groundwater due to the low level of electrification even though water is available at shallow depths (Mukherji et al. 2012). Another institutional impediment is the poor outreach of food procurement in eastern Indian states (Kishore 2004). In response, the Indian Council of Agricultural Research has launched a program called the "Second Green Revolution" in Eastern India (Bhatt et al. 2016) to improve the productivity of crops like rice and wheat.

Groundwater Sector Initiatives

In view of the precarious groundwater situation in many Indian states, several initiatives have been undertaken to enhance groundwater supply or reduce its demand. Supply-side interventions have involved on-farm water harvesting through the construction of small ponds and tanks and related watershed management interventions (Everard 2015). While these have had significant impacts on water availability at the local scale, all water harvesting accomplishes at the basin scale is to reallocate water among users (upstream versus downstream), and among different hydrological units (groundwater versus surface water) without affecting the total amount of water in the system.

Demand-side interventions, that is, interventions aimed at reducing demand for groundwater, have also been tried. These interventions include adoption of microirrigation technologies, laser levelers, and on-farm agricultural water management measures including conservation agriculture and SRI or "system of rice intensification" (Singh et al. 2015). Policy measures have also been tried such as the law to postpone the date of paddy transplantation in Punjab by one month to reduce groundwater pumping.

The government of Punjab initiative to postpone paddy transplantation from mid-May to mid-June has led to a substantial reduction in pumped groundwater because delayed transplantation allows farmers to take advantage of monsoon rains (Tripathi, Mishra, and Verma 2016). However, a constellation of factors, including less time between paddy harvest and sowing wheat and the unavailability of labor coupled with atmospheric conditions prevalent in October–November means that farmers' practice of paddy stubble burning has created a new crisis of high air pollution over most parts of northwestern India (Sawlani et al. 2019). Air pollution can be mitigated through adoption of zero tillage farming and technologies like "happy seeders" (Sidhu et al. 2015), and adoption of shorter duration varieties of paddy (Singh et al. 2015). Adoption of laser levelers in Punjab has led to better water-use efficiency (Larson, Sekhri, and Sidhu 2016). To sum up, most demand-side interventions have been able to reduce on-farm water use, however, the actual extent of water savings depends on whether farmers have additional land where they can use this saved water for expanding irrigation.

In such cases, there have been no water savings in aggregate terms and in many instances, total water use may have gone up (Van der Kooij et al. 2013).

A third set of groundwater interventions include community mobilization for participatory groundwater management (PGWM). PGWM has been tried in some states (Jadeja et al. 2018; Joshi, Kulkarni, and Aslekar 2019). Research has shown that farmers' understanding of groundwater resources increased when exposed to community-based training (Meinzen-Dick et al. 2018). However, the efficacy of PGWM in reducing groundwater extraction is not self-evident within the overall nexus context where farmers get free electricity in several states or get a guaranteed high price for water-intensive crops like paddy or sugarcane.

Electricity and Energy Initiatives Including the Current Focus on Solar Irrigation Pumps

Indirect management of groundwater through electricity reforms has been a long-standing area of interest by researchers from the International Water Management Institute (IWMI; Shah 2009; Shah, Giordano, and Mukherji 2012). For example, annual groundwater withdrawal for agriculture in some of the most overexploited areas can fall by 12–20 km^3 just by eliminating electricity subsidies in nine overexploited groundwater states (Shah, Giordano, and Mukherji 2012). As described earlier, unmetered and subsidized agricultural electricity use was one reason for the financial problems of the SEBs. After the electricity reforms of 2003, many of the restructured distribution companies (DISCOMS) tried to reform the supply of agricultural electricity. The political strength of farmers' lobbies in different states determined which reforms were possible and which were not. For example, none of the major Indian states except West Bengal were able to meter agricultural groundwater users because of strident protests by farmers (Mukherji 2006).

The state of West Bengal implemented universal metering of agricultural electricity connections. They also adopted state of the art, tamper-proof meters, time-of-day metering for demand management during peak load time, and quickly rolled out implementation of 100% metering within a short span of two years from 2007–2009. Early assessment of this intervention found an overall decrease in irrigation during the rainy season paddy, without affecting yields, and a decrease in irrigation by water buyers for the summer season paddy, with some decrease in yields, showing that the impact of metering on groundwater use was mediated through pump ownership (Meenakshi et al. 2013). Given that water buyers are small-scale farmers, metering affected them adversely (Mukherji et al. 2009; Meenakshi et al. 2013). In 2011, after the relaxation of rules regarding electrification in the Groundwater Act of 2005 of West Bengal (Mukherji et al. 2012), the number of electricity connections went up more than threefold, from roughly 94,087 in 2008 to 307,710 in 2019. A recent evaluation of such a phenomenal increase in electrification of agricultural groundwater structures in West Bengal showed that high electricity tariffs, coupled with the low market price of summer paddy and the absence of an effective public procurement system have led to lower than expected benefits from electrification (Mukherji et al. 2020). This has led some scholars to argue for different electricity tariff systems in areas of groundwater abundance like West Bengal (Sidhu et al. 2020). Elsewhere in India, field experiments to measure the impact of metering on groundwater use showed no perceptible savings in groundwater because farmers simply expanded their irrigated area (Fishman et al. 2016).

Other states in India facing the problem of groundwater overexploitation have undertaken reforms aimed at rationing electricity supply. Gujarat (Verma and Shah 2008), Punjab and Karnataka (Mukherji 2017) have undertaken feeder segregation and effectively rationed electricity supply for agricultural users. Some programs, like Gujarat's *Jyotirgram Yojana* (JGY) were initially deemed successful in improving electricity supply quality and reducing groundwater extraction (Verma and Shah 2008), although later studies found no long-term impacts on groundwater tables (Chindarkar and Grafton 2019). In Punjab, feeder segregation, and a host of other measures like high-voltage distribution systems, improved electricity-related outcomes, but those measures did not have any discernible impact on groundwater use because of the increasing number of electric wells in the state (Mukherji 2017). In Karnataka, even electricity-related benefits were not achieved due to implementation and design failures, showing the importance of overall governance and political will in implementing reforms (Mukherji 2017). While it is beyond the scope of this paper to discuss the political economy of electricity reforms in India, the point is that the groundwater consequences of electricity reforms are almost never considered explicitly by energy sector officials. This is because managing groundwater has never been a stated goal of electricity utilities, even though they are possibly the most well equipped to do so. This is where nexus thinking is useful.

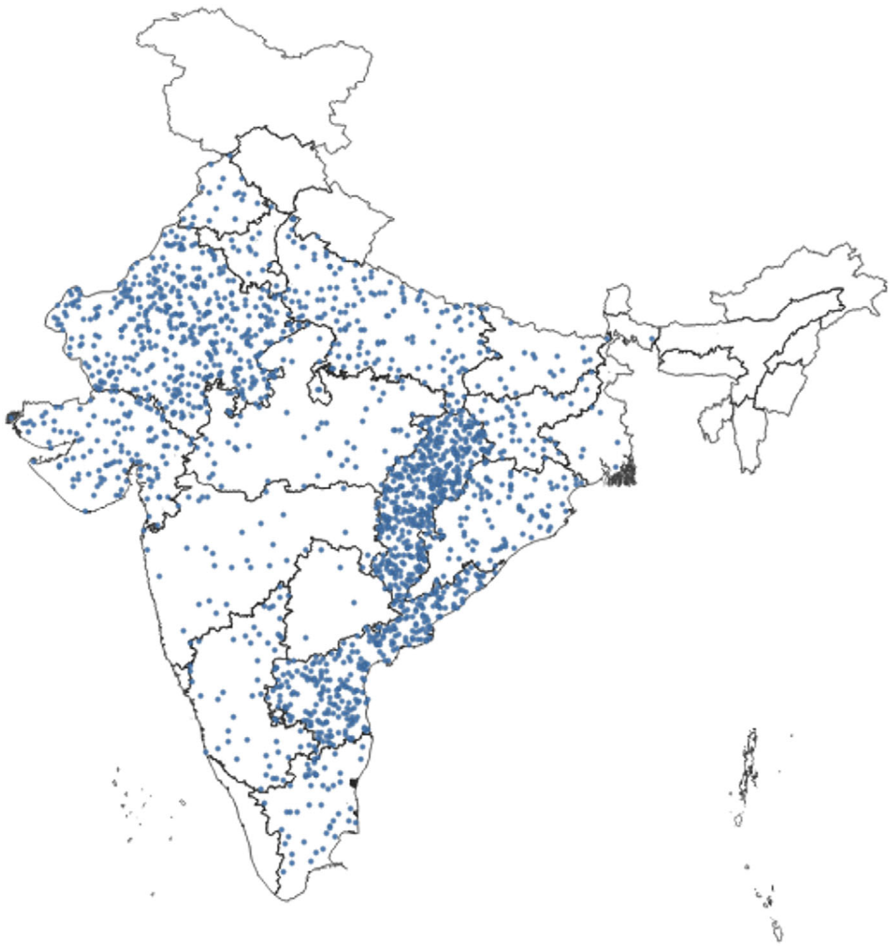
The latest development is the introduction of solar irrigation pumps (SIPs). SIPs are an attractive alternative to diesel and electric pumps and have several cobenefits, but the groundwater implications are not always self-evident. DISCOMs in nine critical groundwater states where agricultural electricity is a large part of their overall load see SIPs as a way of reducing their subsidy burden (Shah et al. 2018). It is not surprising that more than 80% of the roughly 180,000 SIPs in India are in states which already have a precarious groundwater condition (see figures 4 and 6). Evidence of the perverse WEF nexus policies in India can be seen in the paradoxical situation, where farmers in water scarce states have adopted SIPs, while farmers in water abundant eastern India have not.

In the State of Rajasthan, SIPs have improved farm incomes, but overall groundwater extraction has increased substantially (Gupta 2019). Some states, like Gujarat, have introduced schemes whereby farmers can connect their SIPs to the electricity grid and sell excess electricity instead of pumping groundwater (Shah et al. 2018). A national scheme called *Pradhan Mantri Kisan Urja Suraksha Utthan Mahabhiyan*, more popularly known by its acronym KUSUM, also has a similar provision. Whether or not grid connection of pumps will reduce overall groundwater extraction remains a question. The answer will depend on several factors, including the price at which farmers can sell electricity.

Conclusion and Policy Implications

This paper traces the historical evolution of WEF policies in the post Green Revolution period and weaves a narrative of how these interlinked policies have led to several suboptimal outcomes in each of the sectors. These include

Figure 6 Distribution of solar irrigation pumps in India, 2018 [Color figure can be viewed at wileyonlinelibrary.com]



poor nutritional outcomes despite high food production in the food sector, unsustainable groundwater trends in large parts of India, and the poor financial health of electricity utilities. The paper shows how it is possible, through careful policy changes, to reverse some of these unsustainable trends.

Reforming India's food policy and safety net programs that provide subsidized access to food to vulnerable populations from a calorie-centric approach to a more nutrition-centric approach can provide a powerful incentive for growing less water intensive but more nutritious crops like nutri-cereals. This could potentially reduce up to 33% of the current water use (Davis et al. 2018) and lead to a lower carbon footprint for agriculture (Rao et al. 2018). For this change to happen, we will need concomitant changes in the food procurement system whereby nutri-cereals fetch good prices. The State of Karnataka has included millets in their list of procurement crops, yet experience has been mixed because the open market price of millets was found to be higher than procurement prices set by the government (Raju et al. 2018). Some states, like Odisha, have announced the incorporation of nutri-cereals in their social welfare schemes. If other states do the same, it will create a powerful incentive for farmers to move away from water intensive to less water intensive but more nutritious crops.

Reforming India's water system will also necessitate moving away from the false dichotomy between groundwater and surface water and treat water resources as a unified entity. This will help refocus attention on reforming surface irrigation bureaucracy (Srinivasan and Lele 2017). Groundwater depletion and moving away from water-intensive crops can provide the needed impetus for reform of surface irrigation bureaucracy. India can learn from China about ways of incentivizing canal irrigation managers to provide better irrigation services (Lele 2020).

All these reforms underpin the need for greater investments in research and development, for instance, in better seed varieties suited to the agro-ecology of eastern India, or reducing yield variability in dryland crops, as well as a better understanding of the political economy underpinning these reforms. Another area of emphasis should be the rigorous evaluation of the multitude of government programs that have been launched to tackle India's WEF problems. Too few of these national or state-level programs are carefully evaluated. Current policies around grid connection of solar pumps and the hypothesis that grid connections will lead to lower groundwater extraction is a subject of ongoing evaluation by IWMI. Given the complexity of the WEF nexus, it is important to better understand the synergies and trade-offs. Investing in more nuanced research is one way of doing this.

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