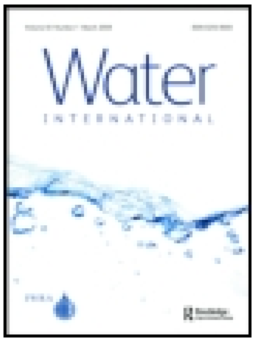

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Assessing India’s drip-irrigation boom: efficiency, climate change and groundwater policy

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Assessing India's drip-irrigation boom: efficiency, climate change and groundwater policy

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ABSTRACT
This article draws on a case from the north-western Indian state of Rajasthan to examine whether drip irrigation saves water. Drip irrigation is being promoted to preserve groundwater and enhance resilience to climate change. However, the article finds that in the absence of regulations over groundwater abstraction, farmers acquire drip irrigation to intensify production rather than to conserve water. This occurs in a political and economic context where farmers are incentivized to do so, further exacerbating groundwater overdraft. The article concludes with a discussion of drip irrigation's impact on farmers' livelihoods and its implications for groundwater policy.

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Drip irrigation; groundwater policy; efficiency; climate change; political economy; political ecology; Rajasthan; India

Introduction

Groundwater depletion is widespread in both semi-arid and humid regions of the world, while global climate change is predicted to exacerbate already dwindling groundwater aquifers by disrupting recharge rates (Aeschbach-Hertig & Gleeson, 2012; Taylor et al., 2013). This is particularly troubling for the future of groundwater-based irrigation, which currently accounts for 67% of groundwater withdrawals globally (IGRAC, 2010; Siebert et al., 2010). State water agencies around the world, as well as international water organizations, agree that the amount of groundwater withdrawn for irrigation must be reduced to reverse groundwater overdraft and to free up water for other uses. Yet given growing food security needs, this must happen while also raising agricultural productivity (Berbel & Mateos, 2014). Given that in many places it is politically contentious or even seemingly impossible to pass new groundwater-use regulations (Fishman, Devineni, & Raman, 2015; Narayanamoorthy, 2004), the focus on enhancing the efficiency of groundwater irrigation immediately through the deployment of new water-conserving technologies is taking centre stage.

Drip irrigation, which supplies water directly to plant stems or roots, is presented as a way to meet these objectives. Proponents have asserted that drip irrigation can double water-use efficiency compared to conventional, sprinkler irrigation systems (Worldwatch Institute, 2013). Over the past 20 years, drip irrigation systems have expanded sixfold globally (Worldwatch Institute, 2013) both through private initiatives

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by small and large farmers (IWMI, 2006) but also because of country-level subsidies, which incentivize their adoption by farmers (IWMI, 2006; Pullabhotla, Kumar, & Verma, 2012). Drip-irrigated area now totals over 10.3 million hectares across the world (National Geographic, 2013). Most of this growth has occurred in the arid and semi-arid regions of the United States, India and China, where there is often a primary reliance on groundwater for irrigation and drinking water needs. Today, India leads the world in both the rate of expansion in drip-irrigated area (111-fold over the past two decades) and in area under drip irrigation, with 2 million hectares (National Geographic, 2013). Indian state planners, development donor agencies, and scientists are promoting drip irrigation as a way to reduce groundwater withdrawals, enhance agricultural productivity and mitigate weather variability, while enhancing resilience to climate change (Government of India, 2010, 2014).

Yet while drip irrigation systems may enhance water-use efficiency, they may not actually save water (van der Kooij, Zwarteveen, Boesveld, & Kuper, 2013). For instance, Ward and Pulido-Velazquez (2008) found that the conversion of sprinkler irrigation systems to drip systems in North America actually increased water use via intensification, exacerbating groundwater decline and worsening soil conditions. While the effect of drip irrigation on groundwater and soil conditions is a matter of intense debate (Pei et al., 2015), farmers' rationale at the household level for whether to adopt drip irrigation has received little attention (but see Benouniche, Kuper, Hammani, & Boesveld, 2014) and would yield valuable insights as to the conditions under which the diffusion of drip-irrigation systems leads to more or less water use.

This article examines the multi-scalar political economy of drip-irrigation adoption by focusing on household decision making and government policy in Rajasthan, India. For the former, I rely on interviews with farmers who have recently adopted drip-irrigation systems to examine the specific conditions under which they have adopted these systems and with what goals. With respect to the latter, I examine recent agricultural policies of the government of India, as well as the government of Rajasthan, to understand the policy mechanisms that promote adoption by particular types of farmers.

Theoretically, the article draws on recent research from political ecology focused on irrigation efficiency that highlights the operation of the Jevons paradox (rebound effect) in water-conservation technologies, where more efficient technologies actually lead to greater use of natural resources (Dumont, Mayor, & López-Gunn, 2013). The article argues that gains in productivity as a result of the adoption of drip irrigation systems are not leading to less water use. This is because of the political economy of groundwater irrigation in India, which incentivizes intensification and extension of the irrigated area of commercial, high-water-demand crops. These findings highlight that water-conservation technologies are not politically neutral and will not lead to water conservation on their own or in the absence of new institutional arrangements (groundwater usage rules and laws).

The article proceeds in four further sections. The next section selectively surveys the literature on efficiency, both technical and economic, in groundwater-irrigated agriculture to show how this literature frames efficiency and groundwater abstraction in technical and apolitical terms. This dominant framing, the section argues, would benefit from a focus on the political economy of agricultural production and farmer motivations for the adoption of drip irrigation, both of which condition water use and potential savings. The third section introduces the detailed case study site of Rajasthan, India, by describing the social, physical and political-economic groundwater irrigation landscape, including how this is changing under climate change–induced weather variability. The fourth section draws on empirical research with farmers from 2015 and 2016 to demonstrate the political economy that incentivizes intensification of irrigation, undermining the dominant rationale that drip irrigation will lead to groundwater savings. The fifth section offers a discussion of the political economy of adoption and efficiency, and examines policy mechanisms that could be instituted for efficiency gains and lower water use, while enhancing irrigated agriculture's resilience to climate change. The final section concludes by detailing the lessons that can be drawn from these cases and how they inform water policy.

The political economy of efficiency and farmer adoption in drip irrigation

There is a global consensus among development donor agencies on the need for efficiency gains in irrigated agriculture (Perry, 2007; World Bank, 2014). Yet what we mean by efficiency and whether drip irrigation in the field leads to efficiency gains or not, is much debated (Boelens & Vos, 2012; Lankford, 2012; van der Kooij et al., 2013). Boelens and Vos (2012) identify two basic discussions over water-use efficiency in irrigation: 'technical irrigation efficiency' and 'economic water allocation efficiency' (see also Lankford, 2006, 2012; Molle, Venot, & Hassan, 2008; Perry, 2007). The first is focused on increasing the ratio of water taken up by plants to water applied, or the amount that is 'beneficially used'. In enhancing technical efficiency, the goal has historically been to minimize 'water losses' in conveyance (e.g., leakage, evaporation) in the case of canal irrigation and/or the over-application or misapplication of water in irrigation generally. This notion was popularized by former UN Secretary-General Kofi Annan's proclamation that considering water scarcity and food insecurity, the global water community must find ways to achieve "more crop per drop" in irrigated agriculture. Historically, this has largely been the domain of irrigation engineers, who attempt to engineer more technically efficient irrigation systems, such as drip or micro irrigation, and crop scientists or agronomists who attempt to breed seed cultivars that require less water, while producing more of any given commodity (e.g., grain, tomatoes).

Economic water allocation efficiency, on the other hand, is primarily the domain of neoclassical and/or agricultural economics, which focus on pricing water at its scarcity value by charging water users the full marginal cost of supplying the water (Johansson, Tsur, Roe, & Doukkali, 2002, cited in Boelens & Vos, 2012). The goal of achieving economically efficient irrigation systems with respect to allocation and water use is to, first, generate more economic surplus per unit of water used, and second, to ultimately (re)direct water to uses that produce higher marginal returns per unit of water using pricing mechanisms. Boelens and Vos (2012), drawing on a political ecology framework, identify three main policy problems that arise due to the focus on these two forms of efficiency as panaceas in irrigation. First, 'efficiency' discourses may promote policies and projects that deprive peasant farmers or smallholders of their water use rights (particularly if these are not codified, as in much of India). Second, water policy and project notions that are driven by water experts (water and/or irrigation engineers) and are based on these two forms of efficiency can undermine local water management practices and may undermine livelihood strategies and security. And third, by setting technical and economic efficiency goals that are often unachievable (i.e., attainable only in a controlled laboratory setting or in theory under assumptions of perfect knowledge and competition), smallholders are rendered underachievers according to the norms established by the 'dominant power-knowledge structures'. In this way, farmers themselves are rendered inefficient and their decision making irrational because these goals do not take into account the complex political ecologies (including political economic circumstances) within which farmers make cropping and irrigation decisions (Birkenholtz, 2009). So, for instance, when farmers elect to grow subsistence or fodder crops rather than market commodities, this is viewed as an inefficient allocation of water and therefore an economically irrational outcome, even though it may lead to less water use overall and enhance resiliency to weather perturbations. Indeed, farmers in India have been known to switch from commercial crops to subsistence varieties during times of water scarcity because non-commercial crops are used as fodder for dairy cattle, which produce the main source of protein (milk) for most of the Indian rural population (Birkenholtz, 2009).

I would add to the three critical points identified above that the focus on efficiency in technical and economic terms has two further negative effects. First, the focus on water use efficiency in these two ways renders the issue of reducing groundwater decline through efficiency enhancements in irrigation a technical problem, demanding technical solutions (Birkenholtz, 2014). Following Li (2007), who argues that development interventions tend to transform the domain of these interventions into problems that require technical solutions (what she has termed 'rendering technical'), development experts identify particular problems and connect them to specific solutions. Here it is important to note that 'technical solutions' does not necessarily mean a physical technology but refers to creation of a 'solution' that renders and narrows the domain of intervention with 'specifiable limits and particular characteristics' (Rose, 1999, p. 33). Applied to the case of groundwater irrigation, development and government experts identify a problem – underperforming irrigation systems along lines of technical and/or allocation efficiency – that can be corrected via a specific solution, in this case the dissemination of new drip-irrigation technologies, rather than considering the political economic conditions under which farmers engage in irrigated agriculture. In doing so, the political economy that incentivizes irrigation intensification via more groundwater extraction is rendered opaque (Benouniche et al., 2014). This allows blame for over-extraction to be placed on farmers – directly, due to their supposedly poor production decisions, or via secondary factors, such as electrical subsidies, which are viewed as the prime problem that incentivizes over-extraction (see Shah, Scott, Kishore, & Sharma, 2004 for a discussion). Here both forms of efficiency become apolitical aspirations. This is a particularly salient point in contexts with little or no regulations over groundwater use and/or with little promise of achieving them. This is the case in north-western India.

In these circumstances, adopting a political economy perspective redirects attention both to the need to understand farmer motivations in adopting drip-irrigation systems and the broader political economic context within which farmers are producing commodities. Through this perspective, the precise causal processes that lead to Jevons paradox may be known, which will yield insights on what kinds of new institutions or rules may incentivize farmers to reduce water withdrawals. The article returns to this in the conclusion. Next, we consider the context of groundwater irrigation in Rajasthan, focusing on its social, physical and political-economic character.

Groundwater, climate change and drip irrigation in India

According to Shah (2009), 88–91% of groundwater withdrawals throughout India go towards irrigation. Groundwater decline, due to extraction that exceeds recharge, mostly for irrigation, and its exacerbation due to climate change, is a serious concern. According to data from NASA's Gravity Recovery and Climate Experiment, north-western India had the highest groundwater depletion rates in the world in 2002–08, even though precipitation was above normal for the period (Tiwari, Wahr, & Swenson, 2009). The severe state of groundwater overdraft in north-western India will interact with and probably be exacerbated by climate change–induced perturbations in at least two ways. First, the IPCC predicts a 0.5–1.0 °C rise in average temperatures by 2029 and a 3.5–4.5 °C rise by 2090–99, though warming of up to 5.0 °C has been predicted for the region (Yadav, Kumar, & Rajeevan, 2010). This increase in temperature is expected to be accompanied by an increase in extreme events (drought and significant rainfall episodes), leading to an increase in runoff of up to 40% by 2090–99 (Gosain, Rao, & Basuray, 2006). It is predicted that much of this runoff will not lead to increases in aquifer recharge due to the intensity of the predicted events (where significant rainfall occurs over a short period), coupled with a lack of rainwater harvesting and recharge structures (though the government is trying to expand the number and scope of these structures; see Government of Rajasthan (GOR), 2010). Warmer temperatures, coupled with fewer and more sporadic precipitation events, will lead to both less groundwater recharge and, simultaneously, growth in demand for groundwater irrigation (Shah, 2009).

This severe state of groundwater decline and heavy dependence on groundwater for irrigation has led to calls for both groundwater regulation and enhancing irrigation efficiency throughout India and Rajasthan.

Groundwater in India: regulation and efficiency

The regulation of groundwater in India is the purview of individual states, but the central government does try to provide direction in this regard. The primary means through which this has occurred is via the drafting of 'model bills' at the central-government level and then encouraging states to adopt some form of groundwater regulation based on them. The Model Bill to Regulate and Control the Development and Management of Ground Water was first drafted in 1970. Since then, it has been revised five times, most recently in 2016 (Cullet, 2012, 2014). Various forms of it have been adopted by 13 (of 29) states, though Rajasthan is a notable absence. The low rate of regulatory implementation has led the central government to actively pursue and promote increased efficiency in irrigation as a way to address groundwater overdraft and promote agricultural resiliency in the face of climate change.

The National Action Plan on Climate Change, 2008, was a major step in this regard. The plan created eight new bodies, or missions, of which two focused directly on water and agriculture. The National Mission for Sustainable Agriculture, 2010, recognizes the 'risks to [the] Indian agriculture sector due to climatic variabilities and extreme events' and seeks to 'encourage adoption of technologies for enhancing water use efficiency'. The National Water Mission, 2011, calls for an 'increase in water use efficiency by 20%' to improve climate resilience. Here the action plan combines groundwater decline, climate variability, water-use efficiency and new efficiency-enhancing water technologies as the future of sustainable agriculture and resiliency. Most recently, these goals will be embodied in the new National Bureau of Water Use Efficiency, the establishment of which is expected in the near future (Parsai, 2013). But it must be noted that, while the spectre of climate change is prompting this latest effort, the Indian central government has been actively pursuing drip irrigation as a means to enhance technical efficiency in irrigation since at least the 1980s (see Narayanamoorthy, 2010, for a discussion of the case of Maharashtra, India).

These efforts by the central government mirror the 'global consensus' on the need for efficiency, noted previously (and critiqued) by Boelens and Vos (2012). Under the National Mission for Sustainable Agriculture, 2010, the central government has allocated US$ 235 million (US$ 124 million in 2014–15 alone), targeted directly at encouraging the adoption of micro (including drip) irrigation. Today, micro irrigation has become so important to groundwater and agricultural policy that it now has its own separate government mission: The National Mission on Micro Irrigation (NMMI). The NMMI states that India's micro-irrigation potential is 69 million hectares, and its goal is to fully achieve this potential (up from the current 2 million ha), though a target date has not been specified. Interestingly, the stated goals of the NMMI are more focused on increasing area under drip and micro irrigation than reducing water demand in irrigated agriculture. Yet this remains the goal of the umbrella missions under which the NMMI is operating.

The NMMI allocates funding to individual states on a 50:10:40 basis, where the central government pays 50% of the implementation cost, while state governments and individual 'beneficiary' farmers pay 10% and 40%, respectively. The subsidy packages are implemented by the states, but through a devolved administrative structure that involves the funds making their way through a maze of bureaucratic entities, beginning with the State Level Micro Irrigation Committee and ending five layers down with the village-level *panchayati raj* elected government institutions and local private irrigation dealers. Individual states also have much discretion in how they implement the programmes (Government of India, 2014). Though implementation of the programme continues to evolve almost seasonally, states may add additional subsidies, offer different levels of training and maintenance support, offer loan guarantees and alter the contract process to make it more accessible to the smallest farmers (see also case studies by Kuppannan, Mohan, Kakumanu, & Raman, 2011; Pullabhotla et al., 2012). The subsidies fund 'drip irrigation system' packages (see below) sized by area in 1-hectare increments (up to a maximum of 5 ha per farmer) based on individual farmer applications.

Like much of India, Rajasthan is aggressively pursuing efforts to enhance irrigation efficiency by encouraging the diffusion of drip-irrigation systems. The next section details the socio-ecological context in which this is occurring, while highlighting the evolution of government incentive programmes with farmers' adoption efforts.

Groundwater in Rajasthan: regulation, policy and efficiency

Rajasthan is arid and semi-arid, highly socially differentiated along lines of caste, class and gender, and heavily dependent on groundwater. Indeed, groundwater serves 76% of Rajasthan's irrigated area – 4.4 million hectares – and 80% of domestic water supply (Government of India (GOI), 2014). Groundwater irrigation throughout the state is composed almost entirely of small-scale private farmers with landholdings that range from 0.5 to 20-plus hectares (GOR, 2011). Rajasthan historically has no formal state regulation that limits groundwater pumping or construction wells, including tube-wells (though this is changing, with construction permits now required in some zones). This has led to rapid groundwater decline in the state, where extraction exceeds recharge by at least 410 million m^3 per year (Government of Rajasthan Groundwater Board, personal communication, January 2006).

After years of failed attempts at adopting a version of the central government's Draft Groundwater Bill, the state of Rajasthan finally enacted the Rajasthan State Water Policy, 2010. The policy has at least three features salient for the present article. First, it calls for a reduction in water withdrawals for irrigation from 83% of total water withdrawals to 70%. Second, it seeks to 'optimize water' usage via new water-conservation technologies, stating that 'groundwater will be better utilized ... by facilitating drip irrigation techniques' (GOR, 2010). And third, it calls for greater participation of the private sector in facilitating technical and economic efficiency gains in irrigation and water use (both in irrigation and in other sectors). These three goals are reiterated in a recent report by the World Bank Group's International Finance Corporation, which sees an opportunity in Rajasthan's groundwater decline and irrigation inefficiency, understood as a technical problem: 'Agriculture, which consumes 83% of the state's water resources, presents the single biggest opportunity for water reform [including] a range of water savings interventions by the private sector' (Hooda, 2014, p. 10). Indeed, drip-irrigation design and manufacturing firms such as Jain Irrigation and Netafim-India are working closely with the government of Rajasthan to help farmers apply for state subsidies, and to provide setup and installation expertise. Yet farmers may have objectives other than saving water in using drip irrigation, as will be shown in the following section, which draws on recent qualitative field research.

Farmers' rationale for using drip irrigation: intensification and extending cultivation

The author has been conducting research on conventional irrigation in Rajasthan since 2001 and first noted the existence of drip irrigation on commercial seed farms in the mid-2000s and on non-seed farms by commodity farmers in 2011. The present article relies on in-depth and repeated interviews with 12 drip-irrigating farmers, first in 2015 and then following up with the same farmers in 2016. All farmers acquired their drip-irrigation systems through the government-subsidized NMMI programme over the past few years. As detailed below, the implementation of the NMMI programme in

Rajasthan has been evolving, particularly with respect to subsidy levels. The Government of India (2014) recently evaluated the implementation of the NMMI across a sample of 10 states. While detailing the conclusions of this evaluation is beyond the scope of the present article, the report did conclude that the NMMI application process for farmers in Rajasthan was 'cumbersome' compared to other states and that some of the supplied irrigation equipment was of poor quality. The report recommended that the government of Rajasthan revise its application process to increase the adoption of drip irrigation. While reliable data are not yet available on the total area now under drip irrigation in Rajasthan, one GOI presentation suggested that it has nearly doubled, from 13,104 ha in 2010 to 25,669 ha in 2015 (GOI, 2016).

The findings of the field research presented here indicate three main tensions in the state's desire to reduce groundwater usage in irrigation and enhance climate resilience via the spread of efficiency-enhancing technologies. (1) Farmers primarily adopt drip irrigation to intensify and expand the area under production, to increase production and income. (2) In doing so, they are fully aware that their water demands are growing. with negative impacts on groundwater recharge, despite the state's goal of saving water. (3) All the farmers using drip irrigation in the area were commercial farmers who were able to afford drip irrigation's high initial investment cost and to navigate the cumbersome and sometimes usurious application process for state subsidy. The better ability of commercial farmers to complete the application process and so to benefit from the drip-irrigation subsidy is likely to worsen social-economic disparities between the adopters (who are already relatively well-off) and the non-adopters. Furthermore, these farmers believe that by adopting drip irrigation now and expanding production, they will accrue economic gains that will elude late-adopting farmers. These latter aspects are returned to in the discussion.

This research was conducted in Bassi Tehsil (administrative block) in Jaipur District, about 40 kilometres east of Rajasthan's capital city of Jaipur, towards the city of Agra. Farmers were selected based on a purposeful, snowball sampling technique with the criterion of having adopted a drip-irrigation system. Drip irrigation is still relatively new to the area, and so 12 farmers represented, at the time, nearly the entire population of adopters. All 12 farmers benefited from the drip-irrigation subsidy, which ranged from 70% to 90% of the total cost of the 'drip irrigation system package'. The state government also offers financing directly to farmers to cover their share of the cost, but none applied for or used this financing. This subsidy rate is different from the stated ratio of 50:10:40 as set out in the NMMI because the NMMI grants individual states the leeway to boost subsidy rates to incentivize farmer adoption. Farmers who adopted drip irrigation in 2014 did so with a 90% total subsidy, because the government of Rajasthan was keen to support its diffusion. But in January 2015, the subsidy had declined to 70% after the state government's switch from the Indian National Congress to the Bharatiya Janata Party. This induced farmers who had not yet adopted to wait for the subsidy to rebound back to 90%. The total average cost of the drip irrigation system package for the 12 farmers interviewed in Bassi Tehsil was approximately US$ 2,300 (1.5 lakh rupees) per hectare, after the 90% subsidy.

All the farmers interviewed had adopted drip irrigation with the express purpose of enhancing production through intensification and expansion of their irrigated area. Drip irrigation enabled these farmers to intensify production both by increasing production per unit area and by shortening fallow times (here fallow refers to land left unseeded for at least one growing season). The former is accomplished by reducing the spacing between rows and delivering fertilized irrigation water (fertigation) directly to individual plants. The latter is accomplished by constructing greenhouses over existing fields to enable the production of off-season crops (see below). Further, all 12 farmers interviewed reported no reductions in groundwater pumping time or schedules. Reducing groundwater extraction is not their goal.

One farmer's perspective is illustrative of a general sentiment: 'We went in for the drip to raise productivity. On average, we are getting double the production from previous [flood irrigation methods]' (personal interview with landowner, February 2015). This household in February was growing water-intensive green chilies destined for commercial markets (Figure 1). This raises a number of issues. Clearly, cultivating a water-intensive crop draws into question whether the diffusion of drip irrigation will lead to water savings or, instead, to various forms of intensification, as is the case here. Drip irrigation enables productivity gains via 'more crop per drop', but does not save water, because farmers are not incentivized (or disincentivized) to do so. Another farmer said the next year, 'Formerly, most chilies were grown on the Jodhpur side [western Rajasthan], and they made a lot of money. But now their water is finished. It's gone hard [which is not good for chili production]. Their borewells are at least a thousand feet deep. This makes it too costly [to pump up to grow chilies]. So now we are doing this' (personal interview with landowner, July 2016).

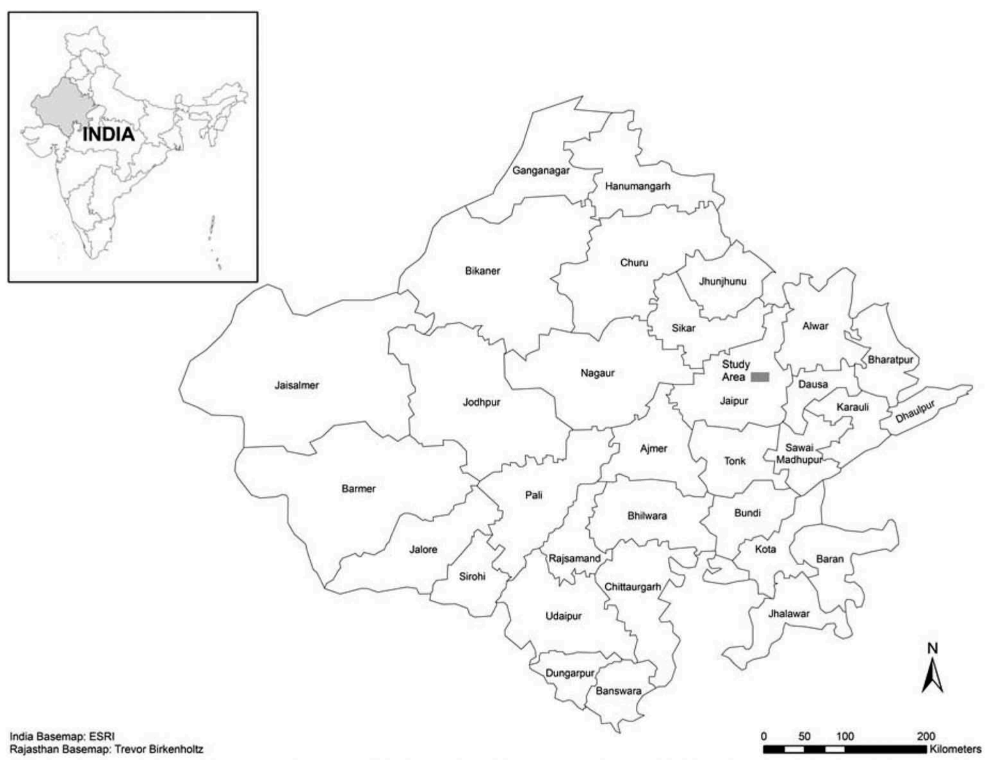

Figure 1. Map of Rajasthan, India, with study area shaded.

The reduction of water-demanding chili production in western Rajasthan created a highly remunerative market opening for chili production in Bassi Tehsil. But due to their water-intensive character, their continued production is likely to reduce groundwater level and quality. And this is already the case, according to one of the 12 farmers interviewed: 'We grew chilies some time back, but the [ground]water became too little, and it was hard. So we stopped and switched to other crops that are less sensitive [to irrigation quality or quantity], such as millet in the summer and wheat or cumin in the winter' (personal communication, March 2015). As others have shown with the adoption of new agricultural technologies, the adoption and diffusion of drip-irrigation technology initially allows the production of new kinds of financially remunerative crops, but the very ecological conditions necessary for this expanded production (groundwater quality in this case) are being undermined through this production (Birkenholtz, 2009).

Farmers are also increasing production through a second form of intensification. They are shortening fallow periods through the construction of greenhouses. Greenhouses allow farmers to essentially gain an extra cropping season in the winter months, going from two crops per year to three. The greenhouses protect crops from the cold, and especially from the occasional frost. Farmers grow a combination of summer vegetables and early-summer tomatoes. For instance, they cultivate okra, which is a summer crop, in the winter. These greenhouses allow farmers to grow off-season crops in an effort to benefit from the higher market prices they fetch during the off season. In both cases – new chili production or greenhouse utilization – farmers are using drip irrigation to produce new kinds of water-demanding crops that fill market niches. On the one hand, this signifies their flexibility to meet changing market conditions and demonstrates acumen. On the other hand, it increases their use of water.

Farmers also extend the area under production by bringing more land under the plough and increasing overall irrigated area. Of the 12 farmers interviewed, landholdings ranged from 1.38 to 6.33 ha, with an average of 3.7 ha. Before adopting drip irrigation, the farmers irrigated, on average, nearly 40% of their cultivatable area. After adopting drip irrigation, this increased to 67% on average. According to the farmers, 'the major limiting factor of further expansion [of irrigated area] is the lack of water. Drip irrigation allows us to expand [area under production] because we can irrigate more.… But we are using about the same amount of water [as we did with conventional irrigation] … or maybe more.' It is reasonable to predict that the irrigated area will continue to increase thanks to drip irrigation. This is likely to increase production but will do little to stem groundwater overdraft.

As further evidence of the desire to increase or expand production, 4 out of the 12 farmers interviewed had also participated in a separate state programme that subsidized the adoption of solar-powered tube-wells. The wells are meant to reduce energy demand in irrigated agriculture, but farmers are using them to increase productivity, in a context where they receive electricity for only eight hours per day, on a day/night alternating basis (Figure 2). Explained one farmer, 'One week we get eight hours of electricity a night, and then the next we get eight hours during the day. When the electricity is at night we run both [the] solar well [during the day] and the regular bore-well [at night]' (personal interview with landowner, July 2016). This is done with the full knowledge that these actions are exacerbating groundwater

Figure 2. Farmer-constructed greenhouse (behind solar panels) to enable off-season crop production.

decline. A second farmer said, 'Water will be depleted [beyond the solar pump] in three years' time.... We will go deeper, or sell' (personal interview with landowner, March 2015). These farmers are knowingly mining groundwater because of a regulatory institutional vacuum in which they are incentivized to extract groundwater both to enhance productivity and to extract groundwater in the near term, before others can. They are also incentivized to continue to raise productivity through the multiple methods of intensification identified above. The motivations of farmers and the conditions under which they elect to adopt drip-irrigation systems are not being considered by state planners. Ultimately, this is leading to continued or even expanded groundwater extraction, rather than water savings. It is to these tensions that we turn in the next section.

Discussion: the rebound effect, efficiency and the political economy of adoption

The broad goals of the Indian state (along with development donor agencies) are to facilitate the adoption and diffusion of drip-irrigation technology to reduce demand for groundwater by enhancing the efficiency of existing irrigation systems. Climate change and rapid groundwater decline serve as the underlying physical conditions and context within which this is occurring. But it also must be remembered that these goals are to be realized largely in the absence of new rules or laws around groundwater abstraction. There are two broad tensions internal to these goals that are undermining their realization. These have to do, first, with the tensions between efficiency and water savings, and, second, between the rationale for farmers to use drip irrigation and the lack of meaningful groundwater regulations.

Overall, the findings presented here demonstrate the operation of the Jevons paradox, or rebound effect, where the adoption of a more technically efficient (in terms of physical productivity or technical efficiency) natural resource technology, in this case drip irrigation, leads to an increase in the use of that natural resource rather than a decrease. One might ask: why wouldn't it? Even though the lion's share of groundwater is drawn for irrigation, the small quantity of water available for irrigation has been an impediment to the further expansion of irrigated area in India. Therefore, when presented with an opportunity to reduce water consumption, while maintaining or even enhancing existing production, farmers see the water savings as a resource that can be reallocated by intensifying cultivation and extending the area under cultivation. Many farm-level studies of drip-irrigation adoption focus on how to promote the further diffusion of drip irrigation through specific policies that will incentivize their adoption, while also enhancing economic and technical efficiency (Friedlander, Tal, & Lazarovitch, 2013; Kulecho & Weatherhead, 2005; Namara, Nagar, & Upadhyay, 2007). Yet, as Venot (2016) clearly demonstrates, the discourse of drip irrigation as a promising climate adaptation technology with the ability to create productive and economic efficiency, while reducing water demand, has become a truism, but needs to be more critically analyzed. As in previous historical moments in the rapid spread of new agricultural technological innovations (e.g., the Green Revolution), drip-irrigation systems are ushering in a new production regime characterized by rising productivity, but at the continued cost of groundwater overdraft.

Second, the continued focus on the technology itself as central to realizing efficiency gains, as well lowering demand for water in irrigation, is illustrated in the tensions between government policies that further reflect the political economy of irrigated agriculture in India. One of the central goals for the National Mission on Sustainable Agriculture (NMSA) is to reduce the water withdrawals for irrigation from more than 90% in India (Shah, 2009) to the 'global norm' of 70% by making irrigation more efficient. Of particular concern for the NMSA is to do this while enhancing food production and increasing the resilience of agriculture to future climate change–related shocks. As I noted above, the central vehicle to accomplish these goals is the smallholder adoption of micro (drip) irrigation systems. This goal is of such importance and centrality to the NMSA that the NMMI was created to realize this express goal, by expanding India's total drip-irrigated area from 2 to 69 million hectares. But the NMMI does not necessarily share the goals of the NMSA; it is focused on expanding the area of irrigation under drip, obscuring the goal of reducing water demand. In this way, neither the NMMI nor adopting farmers explicitly promote or adopt drip irrigation for its ability to reduce demand for water but for its ability to enhance production in a political economic agricultural context where smallholders are attempting to improve their material well-being by increasing agricultural surpluses.

The interaction of these processes, then, has implications for crafting policy that minimizes the rebound effect, while maintaining and even enhancing productive efficiency, in a context of groundwater overdraft and climate change.

Conclusions: policy implications

Drip irrigation is being promoted throughout the world as a climate-adaptive technology that will reduce demand for groundwater and notably enhance the resilience of agriculture in light of ongoing groundwater overdraft and climate change–induced shocks. This article has examined the recent adoption of drip irrigation by farmers in one administrative district of Rajasthan, India, that is undergoing an expansion of drip irrigation. In doing so, it offered a further demonstration of the operation of the Jevons paradox with respect to drip irrigation systems, where the political economy of groundwater-led agriculture incentivizes intensification, which rather than reducing the demand for groundwater is exacerbating groundwater over-extraction.

These findings have a number of policy lessons and implications. First, we need more research focused on understanding what drives the Jevons paradox and what institutional levers may be employed to close the gap between water-use efficiency and intensification dynamics. As with the state's inability to pass groundwater regulation, promoting the adoption of drip-irrigation technology in the absence of any rules governing groundwater use is unlikely to lead to water savings. In the short term, it will lead to enhanced productivity, but in the long term it will lead to further groundwater mining and ultimately to productivity losses. So, too, so-called common sense policy levers, such as increasing the cost of electricity (Scott & Shah, 2004; Shah et al., 2004), are unlikely to reduce groundwater pumping unless farmers are prevented from passing these additional costs to the consumer, thereby reducing their profit margins.

Finally, the Indian National Mission for Sustainable Agriculture, which is the main central-government policy aimed at reducing agricultural demand for groundwater, has two notable flaws. First, it encourages drip and micro irrigation without any consideration of ecological or social resilience in any meaningful way. Here one is supposed to have faith that the diffusion of drip irrigation across the landscape will lead to positive socio-ecological outcomes. Second, there is no mention of the social consequences of the socially uneven adoption of drip irrigation. This has particular importance both for the realization of the development of agrarian livelihoods and for continued agricultural productivity.

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