WATER KNOWLEDGE NOTE

Groundwater Governance and Adoption of Solar-Powered Irrigation Pumps

Experiences from the Eastern Gangetic Plains

Ram Bastakoti, Manita Raut, and
Bhesh Raj Thapa[1]

© Prashanth Vishwanathan / International Water Management Institute.

Solar-powered irrigation pumps (SPIPs) have been promoted in the Eastern Gangetic Plains (EGP) in recent decades, but rates of adoption are low. This case study assesses the evidence from several solar pump business models being adopted in parts of the EGP, particularly eastern Nepal and northern India, and explores how different models perform in various contexts. It documents lessons for increasing farmers' resilience to droughts through better groundwater use by promotion of SPIPs. Groundwater access for agriculture in the past was dependent on diesel and electric pumps, respectively constrained by costs and reliability of energy. Both government and nongovernment agencies have promoted SPIPs in the Ganges basin for irrigation and drinking purposes. SPIPs receive different levels of subsidies across countries and states in the region to facilitate adoption and ensure continuous and timely irrigation, which particularly benefits small and marginal farmers. Because the EGP faces variability in water availability, the SPIPs could help in building drought resilience. However, because low operating costs for SPIPs does little to incentivize farmers to use water efficiently, one critical question is how to balance equitable access to SPIPs while ensuring groundwater overdraft is not perpetuated. Farmers' awareness of efficient water management options is crucial to avoid overextraction of groundwater.

The information in this case study was prepared as part of the South Asia Water Initiative (SAWI) technical assistance project, "Managing Groundwater for Drought Resilience in South Asia." SAWI is a multidonor trust fund supported by the United Kingdom, Australia, and Norway and administered by the World Bank.

WORLD BANK GROUP

Introduction

In recent years, groundwater irrigation has had a large impact on the livelihoods of poor people of South Asia, particularly because of the investments made by private farmers (Rijsberman 2003). The sustainability of such impacts depends on the development of appropriate pro-poor institutions and technologies, but scholars point out that the institutional dimensions that govern groundwater have not been explored in sufficient detail (Mukherji and Shah 2005).

Groundwater irrigation, especially in water-abundant regions such as eastern parts of India, Bangladesh, and Nepal, can be a powerful way to alleviate poverty. In the Ganges basin, groundwater represents a well-recognized resource, shared among the basin countries, and most marginal farmers depend on buying water or renting pumps to meet their irrigation needs (Bastakoti, Sugden, et al. 2017; Jain and Shahidi 2018). The ownership of tubewells and pumps is skewed toward medium and large farmers. Diesel and electric pumps dominated groundwater extraction in the region for many decades. However, solar pumps are emerging as an alternative to fill the gaps of inadequate coverage and unreliable electricity supply as well as expensive diesel options (Jain and Shahidi 2018; Mukherji and Shah 2005; Shah, Durga, et al. 2017). Governments at federal and state levels are providing subsidies to promote the adoption of SPIPs. These pumps have been deployed through different models (private and community-based) along with different financial strategies, mainly varying rates of subsidies (Agrawal and Jain 2018). A number of studies show that SPIPs could help improve access to sustainable irrigation for farmers. However, such efforts reflect a supply-side push that lacks proper considerations of farmers' perspectives (Jain and Shahidi 2018). Promotion of SPIP through different subsidy-led adoption models eases farmers' access to irrigation and could play a role in providing irrigation facilities to deal with climate risks associated with uncertainty in water availability resulting from variable precipitation patterns, delayed onset of monsoons, and long dry spells (Aggarwal et al. 2004; Bastakoti, Bharati, et al. 2017; Li et al. 2011; Moors et al. 2011; Sugden et al. 2014). However, caution should be taken to not accelerate the overextraction of groundwater. Additionally, subsidies promoting SPIPs with little consideration of farmer typology could limit the access of marginal and tenant farmers who make up the majority of the farming population in the region (Bastakoti, Sugden, et al. 2017) and already face disadvantages with respect to tubewell access.

Despite the commitment of both federal and state governments to support solar pumps through capital subsidy schemes, the adoption of SPIPs has been slow because of high initial capital costs, low awareness of farmers, and poorly developed supply chains (Raymond and Jain 2018). In this context, this case study documents how different solar pump adoption models in the region perform. It also provides lessons from the promotion of SPIPs that may help support better groundwater governance, recognizing the opportunities and threats that SPIPs provide.

Extent of Irrigation Use and Policy Environment

The extent of groundwater irrigation is driven by several different factors including social dynamics, energy policies and market economics. These are discussed further in this section.

Social Dynamics and Extent of Groundwater Irrigation

The livelihoods of most of the people in the Ganges basin depend on agriculture (Bastakoti, Bharati et al. 2017; Jain and Shahidi 2018). Access to reliable and affordable irrigation is the key to enhancing agricultural productivity and incomes for farmers.

About 244.8 billion cubic meters of groundwater is available in the Ganges basin, with the highest potential in India (168.7 billion cubic meters), Bangladesh (64.6 billion cubic meters), and Nepal (11.5 billion cubic meters), of which an average of 54 percent has already been developed for irrigation, domestic, industrial, and other purposes (Rajmohan and Prathapar 2013). About 61 percent of the available resources in India, 45 percent in Bangladesh, and 10 percent in Nepal are already in use. Groundwater development for agriculture has been possible in the Ganges basin because of the favorable hydrogeological conditions, fertile soils, and level terrain (Jain et al. 2009). The highest volume of groundwater extraction in the world occurs in the Ganges basin, where it plays a significant role in maintaining the economy and standard of living (Saha et al. 2016). Studies highlight that in recent decades, groundwater irrigation has expanded significantly in South Asia through an increase in the number of groundwater extraction mechanisms (Mukherji and Shah 2005).

The abundance of groundwater has contributed immensely to poverty alleviation, food security, livelihood, and wider socioeconomic development within the basin. Mukherji and Shah (2005) reported that small and marginal farmers account for almost 40 percent of the groundwater-irrigated area. Groundwater is the main source of irrigation, which is dominated by electric and diesel-powered pumps. However, a large majority of small and marginal farmers still lack access to an irrigation facility. Furthermore, groundwater is relatively underutilized in the eastern part of the Ganges basin. Although the reason for this may be economic, it may also be a result of the presence of groundwater contaminants in the region. The incidence of geogenic uranium (Kumar et al. 2018), fluoride (Mukherjee and Singh 2018), and arsenic (Saha and Sahu 2016) in the groundwater of parts of the EGP is known. SPIPs have been introduced in the region since the 2010s and their numbers are still small, but growth is backed by government subsidies and support from national and international nongovernmental organizations (NGOs).

Groundwater Market, Energy, and Policy Framework

Groundwater extraction requires an investment in tubewell installation and pumping equipment that not all farmers can afford. In addition, a high degree of land fragmentation impedes irrigation of all of a farmer's plots using the same tubewell. These are two of the largest constraints regarding groundwater extraction in the Terai region of Nepal and Bihar in India (Bastakoti, Sugden, et al. 2017). A major institutional response to this problem has been the emergence of dynamic and complex informal groundwater markets, evidence of which are found in all South Asian countries including Bangladesh, India, Nepal, and Pakistan. The consensus is that the water markets give irrigation access to those who do not have their own source of irrigation water and thereby helps to increase net irrigation production.

Groundwater markets lack formal institutional arrangement. The role of government has been primarily through regulating electricity and fuel supply. The growth of the groundwater economy has come at the cost of heavy subsidies in electricity often guided by vested political interests, such as in the case of Andhra Pradesh (Shah, Deb, et al. 2003). In another example, energy subsidies in the state of Gujarat led to groundwater overdraft (Shah, Bhatt, et al. 2008). Electricity management was considered an option for groundwater governance responding to such situations (Shah, Bhatt, et al. 2008). From 2003 to 2006, the government of Gujarat launched the *Jyotigram* (lighted village) scheme, which invested US$290 million to separate agricultural electricity feeders from nonagricultural ones and established a tight regime for farm power rationing in the countryside. The Jyotigram scheme has halved the power subsidy to agriculture and reduced groundwater overdraft. It has also produced negative impacts on marginal farmers and the landless who depend on water markets for their access to irrigation, which have become much smaller post-Jyotigram. The government of Nepal is also facilitating groundwater access for farmers with about a 50 percent subsidy per unit (kilowatt-hour) electricity cost for agricultural purposes (Dhital 2015).

Global experience reveals four key policy instruments that seek to regulate the behavior of groundwater users (Shah 2009), including direct administrative regulations, economic instruments, tradable water rights, and participatory aquifer management. The policy and institutional mechanisms to support groundwater use vary from country to country and among states (Saha et al. 2016).

In Nepal, the Water Resources Act of 1992 and Water Resources Regulations of 1993 provide the key water-related legal and regulatory basis for the country but are formulated mainly for surface water and offer no specific provision to regulate groundwater use. An order by the Committee for Underground Water in 1975, chaired by the secretary of the Ministry of Irrigation, mandates surveys, studies, supervision, and monitoring of groundwater, as well as developing an information system and plans for its utilization. The National Water Plan 2005, together with the National Water Resources Strategy 2002, recognizes the importance of groundwater resources for socioeconomic development. The Irrigation Policy (an amendment made in 2013), Groundwater Act 2015, and Renewable Energy Policy 2016 promote the use of renewable energy for groundwater abstraction.

In the federal structure of India, groundwater remains a state responsibility under the constitution. The central government circulated a groundwater bill in 1970, with goals of protecting groundwater resources, taking measures against overexploitation, and ensuring its equitable extraction. The bill was recirculated in 1992, 1996, and 2005 but has had limited success. In the Ganges basin, groundwater is regulated through state government initiatives only in Delhi and West Bengal. The Central Groundwater Authority (CGWA) has been constituted under the Environment Protection Act 1986 to regulate groundwater development and management in the country. It has issued notifications to 162 areas in the country prohibiting construction of new wells, many of these areas being within the Ganges basin. Aside from these notifications, CGWA is imposing conditions on industries seeking to extract groundwater in overexploited areas to invest in artificial recharge structures, particularly in the states where the state governments are not regulating groundwater. The Planning Commission of India, in its report on groundwater management and ownership in 2007, addressed issues related to sustainable groundwater management. The report emphasized the need to develop a framework of groundwater governance.

These policies have focused more specifically on extraction of groundwater than on who accesses it and how it should be utilized. The presence of a groundwater protection act alone cannot regulate groundwater extraction, especially in informal groundwater market settings. A study in northern India showed that the main reasons behind farmers' interest in solar pump adoption are zero operational costs and convenience of use (Jain and Shahidi 2018). The reason behind disinterest in adoption is high capital cost, mostly among small and marginal farmers. Financial support to address high SPIP investment costs and subsidies for irrigation purposes ensure water access for farmers. A critical question is how to promote equitable access to SPIPs without perpetuating or exacerbating groundwater overdraft.

Emergence of SPIPs in the Ganges Basin

Government and nongovernment agencies have promoted SPIPs for both irrigation and drinking purposes. There are different levels of subsidies that vary across countries and states in the Ganges basin, as outlined in this section.

Nepal

Various programs of government organizations and NGOs have promoted SPIPs in Nepal, with both community and individual models (UNDP 2016). The front runners in implementing SPIPs in Nepal are Alternative Energy Promotion Center (AEPC), International Centre for Integrated Mountain Development (ICIMOD), Winrock International, United States Agency for International Development (USAID), International Development Enterprises (iDE), and International Water Management Institute (IWMI).

The AEPC of Nepal targeted installing 500 solar photovoltaic water pumps by 2017 (Kunen et al. 2015). The government of Nepal is providing 60 percent subsidies on solar-powered groundwater pumping systems for irrigation purposes through AEPC. In 2016, the government of Nepal announced a new policy subsidizing renewable energy for commercial and residential customers, which aimed to incentivize accountability and long-term performance, ensuring that renewable energy systems are reliable investments in Nepal. Of the two kinds of subsidies for commercial and residential projects, the government provides subsidies on bank interest. The subsidy of 4.5 percent is provided on interest for commercial projects of more than 1.5 kilowatt-peak and 2.5 percent for residential projects of less than 1.5 kilowatt-peak. The payment for solar is broken down to make it affordable in the long term with a small interest rate in the payment period. In the case of SPIPs, the subsidy is provided under four categories: individual farmers; private company that owns and has leased lands; community based or group of farmers; and special purpose vehicle (SPV). The idea behind SPV is that a private company accesses the subsidy and rents out SPIPs to farmers to increase marginal farmers' access to groundwater.

In comparison to India, where SPIP promotion has been primarily led by state and central departments (see next section for more details), developmental agencies have led interventions in Nepal. Nepal's renewable energy policy has brought a grant model with a 60 percent grant and 40 percent farmer contribution, a grant and loan model with a 60 percent grant and the rest as a loan to farmers, and a pay-as-you-go model in which a 50 percent grant is provided to the solar water service entrepreneur who sells water to farmers (Paul-Bossuet 2017). International organizations such as iDE have promoted small-scale pumps targeting small and marginal farmers, and ICIMOD has piloted SPIP via both community-managed and water entrepreneur–managed modalities. More discussion will follow in the SPIPs as an Alternative section.

India

In India, the Ministry of New and Renewable Energy (MNRE) has promoted solar pumps in different parts of the country for drinking and irrigation purposes since 1992. In subsequent years, the government of India set ambitious targets for expanding the country's renewable energy-generating capacity. In 2010, the government launched the Jawaharlal Nehru National Solar Mission. In 2014, as part of this mission, the MNRE outlined the Solar Pumping Program with the aim to promote the adoption of solar pumps for irrigation and drinking water over five years (Raymond and Jain 2018).

SPIPs in India are implemented mainly through two financing schemes. In the first, farmers receive central financial assistance of 30 percent of the benchmark cost of the pump and possible additional subsidies at the state level. The second is a market-based approach in which the MNRE launched a "credit-linked capital subsidy" scheme through the National Bank for Agricultural and Rural Development (NABARD) in 2014. Under this scheme, the MNRE contributed 40 percent as capital subsidy, beneficiary farmers contributed 20 percent, and the remaining 40 percent is provided to farmers as a loan implemented through NABARD. The capital subsidy scheme initially aimed to support 100,000 pumps in 2014 and reach a target of 1 million by 2021. However, progress was slow because of limited uptake by farmers. As of November 2017, India had a cumulative installation of 142,000 solar pumps. Figure 1 depicts the growth in yearly solar pump installations over 2012 to 2017 (Agrawal and Jain 2018). According to the Council on Energy, Environment and Water (CEEW), the current subsidy-led approach alone will not meet the target (Jain and Shahidi 2018).

The state of Bihar has a particularly conducive environment for adoption of solar-powered irrigation for several reasons. The shallow groundwater table and high solar radiation presents solar as a viable solution for agricultural irrigation, especially given the unreliable nature of electricity in the region. The Bihar state scheme provides a capital subsidy of 60 percent in addition to the MNRE subsidy of 30 percent, requiring farmers to pay just 10 percent for solar water pumps. Bihar has also experimented with a pay-as-you-go model, also referred to as "water as a service," in which the system provider pays for the capital cost of the system and charges an irrigation fee set by the government.

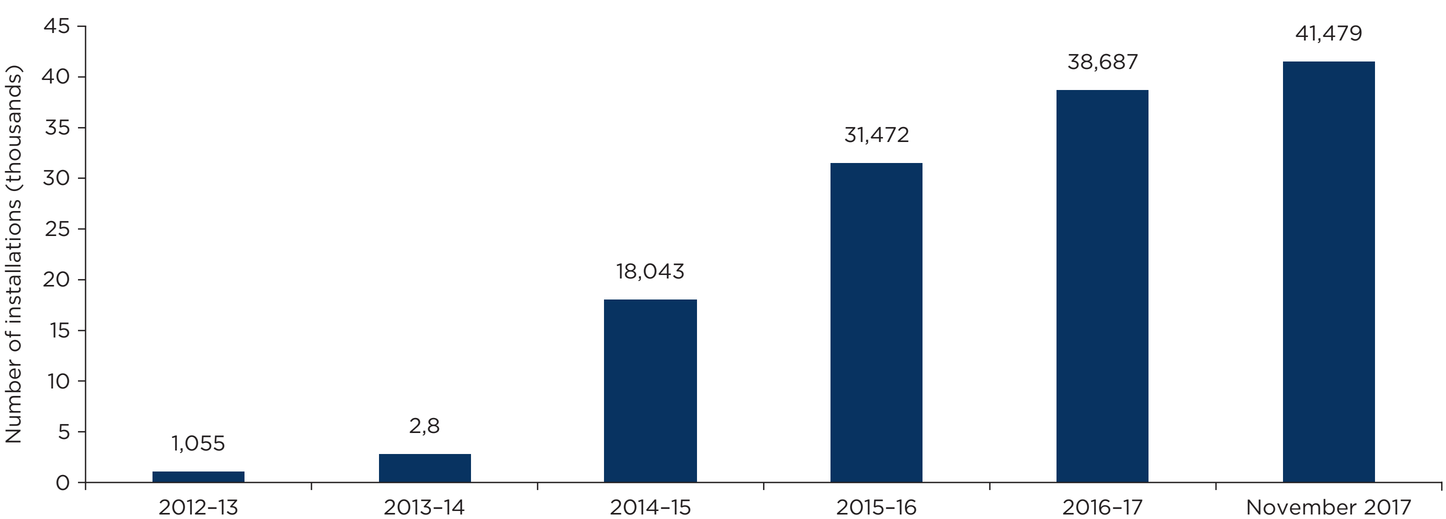
Scale and Governance Models of SPIPs

Three models of SPIPs are in operation in the Ganges basin: an individual-owned model, a community-owned model, and an entrepreneur model (Anonymous 2015). There are also state- and non-state-supported models and a range of pump sizes. Table 1 summarizes SPIPs by scale of operation and governance models.

Small-Scale-Dominated SPIPs in Nepal

The SPIPs installed in different parts of Nepal are largely of small scale, though they represent different governance models. The iDE has been a pioneer in promoting small-scale solar pumps of about 80 watt-peak targeting small and marginal farmers. The system uses the Sunflowerpump, an efficient, versatile, and cost-effective piston pump powered by a photovoltaic panel, which is coupled with affordable, ultra-low-pressure drip irrigation kits to maximize the agricultural output and value of the water pumped. The Sunflower pump is operated either individually or by a small group of farmers as a community model. It is being promoted in several districts of the southern Terai plains of Nepal. IWMI, in collaboration with partners, promoted Sunflower pumps of 80 watt-peak in two villages of the Saptari district in Nepal that face water scarcity in the winter and summer seasons. Those pumps were installed because of the fluctuation of electricity and frequent power cuts coupled with the expensive diesel price. The pumps are managed with a community model composed of five to eight members cultivating less than 1 hectare of land. Both female and male farmers received training on operation and maintenance. These small solar-powered

FIGURE 1. Solar Pump Installations in India, 2012–17



Source: Agrawal and Jain 2018.

TABLE 1. Scale Versus Governance Models of SPIPs in the EGP

Scale of operation	Operating models		
	Individual	Group/community	ISP/entrepreneurship
<1 HP	• Common in Nepal Terai	• Common in Nepal Terai	• None
1–3 HP	• Bihar, India, owned by individual farmer	• Nepal Terai as community model—in some cases supported with battery—surplus energy used in other agricultural purpose • Bihar, India, as community model (part enterprise as well) • West Bengal, India, as community model	• Nepal Terai as enterprise model • Bihar, India, as enterprise model
3–5 HP		• Bihar, India, as community (water-as-a-service) model	• Bihar, India, as enterprise model
>5 HP			• Bihar, India, as enterprise model

Sources: Anonymous 2015; Blunck 2013; Ghose 2015; Paul-Bossuet 2017; Rai 2018; Soman et al. n.d.; UNDP 2016.
Note: EGP = Eastern Gangetic Plains; HP = horsepower; ISP = irrigation service provider; SPIP = solar-powered irrigation pump.

pumps have ensured continuous and timely irrigation. The experience from collective management of the pump has demonstrated that access to irrigation is not only about the size and capacity of solar pumps but also how the system is managed. This included making irrigation schedules among the members and the collection of group funds for repair and maintenance of the system. Similarly, overextraction is a result of not only availability and capacity of solar pumps but also farmers' knowledge of irrigation management. Although farmers initially overirrigated their plot because of increased water availability using the solar pump, they came to adopt efficient water application through continual training and engagement. Training and extension services on efficient water management have the potential to shape farmers' behavior and prevent overabstraction.

The Sunflower pump has gained popularity among smallholders for several reasons. Because of its small size and investment, smallholders can afford to install it and it is easy to operate. It is appropriate to combine with micro-irrigation techniques, particularly for low-water-use commercial crops. Sunflower pumps can be moved easily to different fields and, thus, farmers with scattered parcels of land can use it easily. The key aspect of this technology is that it helps significantly in increasing smallholders' access to groundwater, which is a crucial part of groundwater governance. The low-cost water lifting options combined with micro-irrigation technologies could provide efficient on-farm water management solutions (Namara, Nagar, and Upadhyay 2007).

ICIMOD has piloted medium-scale 1- and 2-horsepower pumps with solar panels of 1,200 watt-peak and 2,400 watt-peak in the eastern Terai district of Nepal. The piloted SPIPs are being operated in two modalities: community-managed and water entrepreneur–managed. Community-managed SPIPs are a 1-horsepower SPIP operated by a farmers' association at the Haripur village of the Saptari district and a 1-horsepower SPIP operated by women farmers at the Rayapur village of Saptari. The 1-horsepower pump (with a 1,200-watt-peak solar panel) piloted in Saptari irrigates about 2 to 3 hectares in a season. It can run for five or six hours with full discharge and one to two hours more with reduced discharge. The system costs US$3,800. Likewise, a 2-horsepower SPIP is being operated by a water seller at the Hardiya village of Saptari under the enterprising model (Paul-Bossuet 2017). To implement these pilots, ICIMOD has rolled out three financing models: subsidy, loan, and rental. In the subsidy model, 40 percent subsidy and 60 percent equity is provided. Under the loan model, 40 percent subsidy, 40 percent loan, and 20 percent equity is provisioned. Monthly usage rental payment is arranged under the rental model.

Likewise, medium-scale SPIPs are promoted by Winrock International through a USAID-funded project in western Terai and mid-hill (lower valley) districts of Nepal. Through coordination with private suppliers, banks, and financial institutions, various business models were devised such as "credit financing, rent to own, water entrepreneurship and vendor financing" (UNDP 2016). One of the systems installed has the capacity of 1,260 watt-peak (1 horsepower) and is used for vegetable farming. A loan of US$3,000 was taken from a local farmers' cooperative, and a grant of US$2,200 was provided. It is managed collectively by 16 farmers in a group called Sitaram Krishi Samuha

(UNDP 2016). The next system was installed in the Surkhet district in 2017, managed by a farmer's cooperative of 30 members. The 2,340-watt-peak modules from China and 2-horsepower AC (alternating current) surface pumps were installed with a water storage tank. The total cost of the system was US$5,170. Another is a relatively large hybrid system installed in 2016 with the capacity of 3,120 watt-peak (3 horsepower) in the Piparkoti village of the Kailali district. It is owned and managed by the 20-member farmer group. It is a system attached with a battery bank used to operate a crop grinder processing unit with a cost of US$7,430 (UNDP 2016).

The community-owned SPIP model being implemented in different parts of Nepal has shown positive outcomes, particularly regarding marginal and tenant farmers' access to irrigation. The partnership among the farmers in terms of financial assistance and group management of the solar equipment is vital. There are challenges to group management because it is continuous work to maintain group dynamics to ensure equitable sharing of the resource. One is the lack of knowledge of repair and maintenance. Because the solar-powered irrigation is in its infancy in these areas, the support systems for repair and maintenance work are still inadequate. The financial support from NGOs is another important aspect in promotion of solar-powered pumps. The high initial installation cost limits farmers' capacity to invest in solar-powered systems, which brings in the question of whether such systems will always require financial support from external agencies.

Medium- and Large-Scale SPIPs with Different Business Models in Bihar and West Bengal

A range of SPIPs have been piloted and promoted in different parts of Bihar, varying in scale of operation and business models. Jain Irrigation Systems Ltd. and PRAN (Preservation and Proliferation of Rural Resources and Nature) Gaya collaborated in August 2013 to pilot SPIPs and drip irrigation in the Rajapur village of the Gaya district in Bihar (Soman, Verma, and Harley n.d.). The pilot project aimed to provide benefits to vulnerable farmers by improving access to irrigation through the use of SPIPs and examining synergies between SPIP and drip irrigation in paddy. A 2.5-horsepower solar pump was provided to seven farmers in a group and managed collectively at a cost of approximately US$8,000. It was a 2.5-horsepower DC (direct current) submersible pump with 2400-watt panels. The women members are responsible for deciding the water user fee and irrigation schedule and carrying out transactions related to the bank. The group collects ₹20 (US$0.29) per month to create a fund for future maintenance. The excess water is sold to neighboring farmers, indicating that it partly operates as an enterprise model as well.

Likewise, GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), in partnership with Claro Energy Pvt. Ltd., has piloted SPIPs under three business models operating under different scales in the Vaishali district of Bihar (Blunck 2013). The largest is a 4-horsepower submersible pump that is owned and managed by a farmers' cooperative under a pay-as-you-go model. The second is a 2-horsepower pump owned by a diesel entrepreneur, and the third is a 1-horsepower surface pump owned by an individual farmer. To roll out these activities, GIZ has carried out training and awareness-raising activities and workshops for key stakeholders. One such example is training bank managers on solar technology and the financial viability of solar pumps. GIZ has demonstrated a community-based solar pump under a pay-as-you-go service model, which is like the water-as-a-service model at the Vaishali district in Bihar. GIZ organized demonstration camps for farmers (Ghose 2015). The pumps installed were 2-horsepower alternating current submersible pumps with a 240-watt panel. The total cost of the system was approximately US$8,548, and the cost of the 200 feet boring was about US$1,887. In 2014, the system served a total number of 147 farmers in a total catchment area of 60 acres with 730 hours of operation.

IWMI has collaborated with partners to pilot medium-scale SPIPs in selected villages of Bihar and West Bengal representing water-scarce situations in winter and summer. Two SPIPs of 3-horsepower capacity are installed in the Bhagwatipur village of the Madhubani district in Bihar. After using the solar pump, farmers could save the cost required to purchase diesel or water from diesel pump owners. Likewise, two 2-horsepower pumps have been piloted, one each in the Dhaloguri village of the Cooch Behar district and in the Uttar Chakoakheti village of Alipurduar district in West Bengal. Both pumps in West Bengal have been promoted through a community-managed model, with one advantage being that farmers save money periodically. These funds work as a contingency to pay for repair and maintenance, so members do not have to contribute additional large amounts for emergencies.

Likewise, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)has been involved in developing and piloting contextualized business models for solar irrigation as off-grid and on-grid models in different parts of India. The off-grid model is applicable to areas with poor or no electric connections. It was developed in the context of Bihar: Although rich in groundwater, electricity is unavailable, so farmers have to use expensive diesel pumps. The cost of using these diesel-powered pumps was one of the reasons for lower agricultural productivity for village farmers. Five-horsepower SPIPs were introduced in the Chakhaji village in the Pusa block of the Samastipur district in Bihar through farmer entrepreneurs. In addition to large solar pumps, buried pipelines were provided to the selected solar irrigation service providers (SISPs) in the village. Aga Khan Rural Support Programme and the IWMI-Tata Trust supported initial investment for installation, including both loans and subsidies. Five individuals are enterprising as SISPs to provide water for 180 acres of land (Rai 2018). Smallholders can irrigate their fields by purchasing water from these SISPs. Water access for irrigation has improved because competition among SISPs in the village keeps water prices low, and so far, some of the diesel-powered pump usage has waned. The cumulative revenue and money saved from not making payments for diesel pump rentals over time has made this model an attractive one. Small land-holding size in Bihar makes the off-grid model an attractive solution. Fragmentation of land parcel means that only one irrigation infrastructure is insufficient to irrigate all cultivated plots, and purchasing irrigation infrastructure is a major financial investment—and an unprofitable one. There are two main advantages with solar water entrepreneurs: Smallholder farmers can avoid the high initial investment, and they can access irrigation at affordable prices.

SPIPs as an Alternative

The suitability of SPIPs as an alternative to existing practices is influenced by economic drivers, adequate technical knowledge, the ownership model and farmer awareness.

Suitability of SPIP for Irrigation

SPIPs are an important technology for irrigation for small and marginal farmers in the dry season in Nepal and India (MIT 2017). SPIPs offer significant opportunities to facilitate irrigation access in an affordable and environmentally sustainable manner while decoupling irrigation from the rising power subsidy burden (Agrawal and Jain 2018). Poor availability of electricity resulting from limited grid connection and power fluctuation, and expensive and greenhouse gas-emitting diesel, positions solar as a suitable alternative for irrigation. The EGP region faces drought almost every year because of the uncertain rainfall pattern, particularly delayed onset of monsoon, and long dry spells, resulting in significant variations in water availability for agriculture (Bastakoti and Bharati 2017); Moors et al. 2011; Sugden et al. 2014). In such a context, SPIPs could play a crucial role in building drought resilience by providing cost-efficient access to irrigation water. An assessment of different types of solar pump technologies and business models available in India for irrigation reveals that the wide variety of solar technology available and limited knowledge of what works best for farmers makes it hard for them to decide on a technology (MIT 2017).

A study conducted in Nepal provides a cost comparison of different systems covering solar, electric, and diesel pumps (Renewable World 2018). The study compared the cost-effectiveness of different pumping technologies, considering the most commonly used solar pumping unit (which has 1,200 Wp (watts peak), a 1.5-horsepower pump, and 5-meter lift height). The life cycle cost (LCC) was calculated over a 20-year period, accounting for up-front, operating, maintenance, and replacement costs at an assumed discount rate of 10 percent. The cost calculation included the overall cost of operation. Likewise, the analysis included calculation of the cost per unit of water for a diesel-powered pump and grid-operated electric pump to deliver the same volume discharge over 20 years. The cost per unit of water was calculated considering LCC at a different capacity utilization factor (CUF). The cost per unit of water for a diesel pump and an electric pump was calculated for different scenarios matching the equivalent volume of water pumped by a solar pump at different CUFs. Table 2 compares the cost per unit of water for different energy options with different utilization factors. Results show that solar-powered pumps could give better results at a higher capacity utilization factor but seem inefficient at a lower CUF. Prices are calculated based on the electric grid in the nearby land parcel, which is not common in the EGP. Hence, off-grid farmers have the choice of either solar or diesel, and SPIPs are the best option for them beyond a 50 percent utilization factor.

Raymond and Jain (2018) reported that an off-grid farmer could choose to own a diesel or solar pump. They reveal that without government subsidy, a stand-alone solar pump is less attractive to a farmer than diesel, whereas a 30 percent government subsidy makes ownership of a solar pump more attractive for a farmer compared to owning a diesel pump from a lifetime cost perspective. This situation depends on a farmer's annual irrigation requirement and

TABLE 2. Cost Comparison for Different Energy Options in Nepal

Cost per unit of water (NPRs/m³) (considering 5% increment in every fifth year) Pump type	Capacity utilization factor (%)				
	10	25	50	70	90
Solar-powered pump	24.40	9.80	5.00	3.60	2.83
Diesel pump	8.80	6.39	5.51	5.48	5.26
Grid electric pump	5.58	3.81	3.14	3.06	2.90

Source: Renewable World 2018.
Note: m^3 = cubic meter; NPR = Nepalese Rupee (US$107)

TABLE 3. Ownership Models and Their Advantages and Disadvantages

Ownership model	Advantages	Disadvantages
Individual-owned	• Suitable for large farmers	• High investment cost • Pump may not operate at efficient scale
Collective	• Reduces up-front cost for the pump ownership • Farmers can have a group fund to pay for maintenance/repair expenses	• Powerful farmers may dominate marginal and tenant farmers in terms of pump usage • Essential for the cooperative members to have contiguous plots while one single farmer may have land in multiple places in Bihar and Nepal Terai
Entrepreneur (pay-as-you-go)	• Suitable for resource-constrained farmers, especially marginal and tenants because they can purchase water when in need for service without bearing the system cost • Government-fixed rental charges can better serve farmers paying higher irrigation rental charges in informal groundwater market • Familiar model because it is like existing water markets	• High investment cost • Difficult to get "entrepreneur"

the price of diesel. An increase in the annual pumping hours makes solar more attractive than diesel, particularly for small and marginal farmers dependent on pump rental or purchasing water. For them, the shift to solar pumps could be an economically attractive option in the long run, but the up-front cost may remain a barrier to solar pump ownership.

Studies show that the capital cost of a solar pump is well beyond the normal financial means of a small farmer. In such context, the government could put efforts on enhancing marginal farmers' affordability. Innovations in highly efficient, low-cost solar pumps and financing may improve the affordability of pump ownership for marginal farmers. Suitability of SPIPs could be enhanced through connecting the solar pump to the grid so that they can sell surplus energy and earn additional revenue. Though not yet in practice in EGP, a pilot study in the Dhundi village of the Gujarat district has demonstrated that grid-connected solar generates additional revenue for farmers (Shah, Durga, et al. 2017).

Different ownership models have advantages as well as disadvantages and thus provide a range of policy lessons (table 3). Although the individual-owned model seems better for large farmers, the initial investment cost could still hinder the adoption of SPIPs. The constraints associated with initial investment could be better handled through the collective model. Both collective and entrepreneur models could be a better option for resource-poor farmers. But the collective model also could fall in the trap of elite capture by better-off farmers; thus, marginal farmers could once again be sidelined. Some examples of better functioning entrepreneur models were seen. But such entrepreneurs should be able to arrange operating resources; they should be risk-takers and motivated to work in rural areas. Therefore, finding such entrepreneurs in rural areas is a challenge.

Because knowledge is limited on what works best for them, farmers tend to purchase expensive solar with higher capacity than they need. One of the ways to better assist farmers to adopt expensive solar equipment is through a combination of subsidizing solar and paying for excess electricity produced as is being rolled out in Gujarat (MIT 2017). Efficient water use is important to optimize the food-water-energy nexus, and the solar pump system should be installed through appropriate governmental policies. A pump sizing tool, such as that developed by the Comprehensive Initiative on Technology Evaluation (CITE), will help farmers better understand the pump size they need to buy according to their field size and water requirement (MIT 2017).

An individually owned and operated off-grid solar model for irrigation helps farmers irrigate more easily and in a less expensive way than through diesel and electric pumps. Although solar incurs higher costs in the beginning, in the long run, irrigation will be cheaper through a solar pump than through a diesel pump and infrequent electric supply. However, this also means that the individually owned solar pump entrepreneurs could end up overextracting water by supplying to more farmers, particularly if there is a desire to recover the installation cost faster. The on-grid models, like those of Gujarat, could be more effective in preventing groundwater overextraction because farmers can sell excess power to the connected grid.

There is more than one way to recover the up-front cost of SPIPs. Farmers can also improve the economics of solar pump ownership by selling water to neighbors or renting out the pump. The feasibility of water sales depends on the proximity of other farms, the timing of local irrigation needs, portability of the pump, and the availability of other irrigation options such as government tubewells. Alternately, farmers can improve the utilization of solar pumps by using the power in other productive activities such as post-harvest processing, which was observed in one case from Nepal.

Awareness, Perceptions, and Adoption of SPIPs

The choice of pump size and size of farmers' plots have been shown to be correlated (Jain and Shahidi 2018). Marginal farmers mostly preferred SPIPs of 3 horsepower, whereas among the medium to large farmers, 5 horsepower was the most popular choice.

Regarding the different models for SPIPs, normally the solar pumps are deployed as a conventional individual ownership model, though some other models are also adopted. The individual ownership model may continue to remain the main one, especially with large farmers. High capital cost for installation is one of the key barriers for farmers not being interested in adopting solar pumps. However, the practice of agriculture as a primary source of income, and farmers' future investment plans for renting out farm machinery, still motivates them to adopt the SPIPs. Because the high capital cost could be a barrier for most small and marginal farmers, they are interested particularly in a joint ownership model. A study conducted in 10 districts of Uttar Pradesh showed that about 20 percent of the farmers prefer a joint ownership model for solar pumps, in which they could share the cost of purchase. The majority of farmers preferred buying water for irrigation if it is available at an economical rate, indicating that the water-as-a-service (enterprise) model is the preferred model for solar pumps (Jain and Shahidi 2018), where the price is competitive relative to the prevailing local water market prices.

A study carried out by CEEW in Uttar Pradesh reveals that only 27 percent of farmers had heard of solar pumps, less than 15 percent had seen a solar pump in reality or on television, and only 2 percent had heard of government schemes related to solar pumps (Jain and Shahidi 2018). This result indicates a low level of penetration of SPIPs in the Gangetic region. MNRE estimates show that, of the nearly 30 million irrigation pumps in use throughout the country, only 0.4 percent are solar (MNRE 2017). The low penetration could be because only a limited number of farmers are aware of the government schemes for installing SPIPs, indicating a major awareness gap in this domain.

Farmers' perception of the successful operation of a solar pump increased with demonstrations of its use (Jain and Shahidi 2018). This finding corroborates the observations made in IWMI-led pilot intervention sites in Madhubani, Bihar, and Cooch Behar as well as Alipur districts of West Bengal that farmers develop positive views about operation after seeing the solar pumps in action. Many farmers showed interest in adopting solar pumps particularly because of zero operational cost and convenience of use.

In the EGP, as a result of male out-migration, women need to handle new agricultural responsibilities. They face challenges in irrigating their plots with diesel pumps because they are difficult to operate. In such a context, women farmers have been using solar pumps in combination with proper training in the operation of SPIPs (Bastakoti, Sugden, et al. 2017). Operation of a solar pump requires less labor, which has made solar pumps an attractive, easy, and cost-effective alternative in comparison to diesel pumps. The range of solar pump sizes can cater to marginal, small, medium, as well as large farmers. Different solar business models laid out by ICIMOD (as discussed in the previous section) can be more appropriate for farmers with limited financial capacity. Furthermore, organizing marginal and tenant farmers in groups through consolidating land together, installing solar pumps, and operating the system collectively have addressed challenges associated with access to water.

If SPIPs are not managed adequately, there are risks of unsustainable water use (Hartung and Pluschke 2018). Increased access to cheap groundwater through SPIPs may result in overapplication of water in the field, increasing farm area under irrigation, shifting to high-value water-intensive crops, and selling water to neighboring farmers (Hartung and Pluschke 2018). In such situations, it is crucial for the government in India and Nepal to recognize water overdraft–related risks from the beginning for the sustainable use of SPIP technologies at the outset, from the design and financing stages. Smart and integrated subsidy schemes that bring together benefits from increased water access and efficient use of water and energy could be promoted (Schmalensee 2015).

Key Lessons for Improved Groundwater Governance

Subsidies for irrigation purposes is not a new phenomenon. Post–green revolution agricultural and irrigation subsidies helped Indian farmers access and utilize groundwater to some extent. However, it is also true that subsidies on electricity in Indian States, such as Punjab, resulted in an alarming rate of groundwater depletion (Schmalensee 2015). Several other parts of India also face severe water stress and declining groundwater level. One of the reasons is widespread adoption of inefficient pumps resulting from highly subsidized, low-tariff electricity mostly at flat rates (Dhawan 2017). The consequent decrease in water table further increased the use of energy for pumping groundwater from deeper levels. The important question is what India and Nepal can learn from past experiences going forward in terms of greater adoption of SPIPs.

SPIP systems require high initial investment, and purchasing them without subsidy and support can make the systems unaffordable, particularly for marginal and small farmers. Results discussed in previous sections show that different models of deploying solar pumps should be context- and farmer-specific. Because the emergence of SPIPs is still in its infancy, lessons can be drawn from the water governance examples from the past as well as from the evolving practices adopted by governmental and nongovernmental agencies in Nepal and India. As diverse as the farmer groups are in these regions, the scale of SPIP and governance mechanisms are equally different. There is no one best SPIP adoption method. Hence, the installation, adoption, and replication of SPIP should be context-specific, as indicated in table 4, which summarizes the suitability of different operating models. With the technological advancement resulting in the emergence of new SPIP models, it is comparatively easy to pursue context-specific SPIP programs. For example, if the farmers are small and marginal, a collective approach can be a good fit. For fragmented plots, which seem to be common in the EGP, even the solar enterprise model on an agreed fee can be a good option. However, in the off-grid model, chances of overextraction of groundwater are higher because of the limit on incentives (for example, selling excess power to the grid). Although subsidy-led SPIP programs reduce the cost of water extraction for farmers on one hand, the "free water extraction" could lead to unsustainable water withdrawal practices on the other. Hence, proper regulatory mechanisms are necessary to withdraw water within a prescribed limit.

TABLE 4. Conditions for Different Operating Models

Operating model	Types of farmers best suited	Landholding size (ha)	Crop type and farming
Individual	Large	>2	Conventional farming with cereals, sugarcane, and others
Collective	Small and marginal including landless	>0.5 and landless	Commercial farming with high-value crops
Entrepreneur (pay-as-you-go)	Small and marginal	0.5–2.0	Commercial farming with high-value crops, market-targeted production

Note: ha = hectare.

The water-as-a-service model with the involvement of village-level entrepreneurs is a promising SPIP model to both improve the utilization of solar pumps and provide irrigation access to marginal farmers. In the areas with a dominance of diesel pumps for renting or selling water, a solar-based water-as-a-service model could have a payback of two to four years. But, if the farmers have access to reliable electric grid connection, the electric pump would generate the most profit for the entrepreneur using subsidized agricultural connection because electricity is subsidized for agricultural use in most parts of the Ganges basin. On the other hand, in the areas lacking electric grid connections, diesel and solar pumps would be the only options for such entrepreneurs. Although the entrepreneurs will not have any option to sell surplus energy, they could generate additional revenue using that surplus energy in other activities such as post-harvesting activities. The entrepreneurs could possibly displace the diesel pump owners as well.

Likewise, in the areas lacking electric grid connections, individually owned medium-scale solar pump deployment could also be a better option. Encouraging pump sharing by marginal farmers could increase the utilization of solar pumps. By doing so, governments would be able to realize increased impacts of their efforts (such as subsidies) and, at the same time, could consider options for creating market-based solutions for efficient and judicious use of groundwater. It should, however, be noted that the viability of sharing the solar pump in a group, and the significance of the revenue from such a system, is sensitive to the timing of local irrigation needs.

Concerning the financing of the SPIPs, it could be difficult to promote a subsidy-led approach. Governments may find it not so easy to deploy SPIPs at scale, given their high up-front cost. For the large-scale deployment of solar pumps, credit-based delivery models would be crucial. It indicates the need for long-term finance being able to ensure widespread adoption of SPIPs. However, several risks and operational challenges may constrain flow of long-term finance for SPIPs.

We can draw some lessons from those cases that could help improve groundwater governance.

- In many parts of the Ganges basin, farmers still rely on expensive diesel (even availability of fuel is a concern, like Nepal) and an unreliable electricity supply. In such a situation, promoting alternate energy options such as SPIPs could provide a viable option. Solar options could be considered as a climate-smart option as well as crucial in enhancing drought resilience, although the initial capital for solar investment is quite high and could be a factor in restricting the adoption especially for marginal and tenant farmers. In such a situation, the range of solar pump sizes can cater to marginal, small, medium, as well as large farmers. Adoption of different solar business models coupled with a range of collective/community models can be more appropriate for farmers with limited financial capacity.
- Farm size and investment capacity of farmers are crucial for the installation of any groundwater extraction mechanism. This suggests that collective/community models could be an option for smallholders through which their consolidated efforts can help improve access to groundwater. The shared investment to install an SPIP system and collective water allocation mechanisms help address investment-related challenges.
- Collective sharing of water infrastructure can lead to conflict among farmers, which can undermine the idea of cost and water sharing. Hence, careful methods should be put in play to formulate rules of collective action. This could also be a way to address the irrigation challenges in fragmented land parcels, which is one of the major problems in this part of the world.
- Accessing irrigation is one aspect of sustainable water use, and promotion of SPIP is one way to go about it. Efficient groundwater use depends on an appropriate combination of micro-irrigation technologies with SPIPs. This could help achieve higher efficiency with less use of water.
- Institutional options that facilitate farmers' access to government support services could be considered. Examples include government provision of subsidies for solar installations such as through AEPC in Nepal and federal and state government–financed subsidies in India.
- Provision of after-sales service is crucial for operation and maintenance of the system.
- Promotion of options with low operational cost could aggravate the problem of overextraction of groundwater through uncontrolled pumping. Therefore, some form of regulatory mechanism to manage the rational use of groundwater resources is needed.

Awareness building among farmers regarding the capacity of solar systems is essential. At present, the sources of information on solar pumps are largely solar companies. Farmers need to know what system would best cater to their requirements considering their size of land and irrigation needs. This eliminates the issue of overinvestment in the system.

Conclusion and Policy Implications

Groundwater in the Ganges basin offers great opportunities for sustaining the livelihoods of the people. SPIPs have the potential to enhance access to irrigation, promote low-carbon agriculture, and improve farmers' resilience against climate change. SPIPs could be scaled up by adopting context-specific strategies and focusing on improving awareness about the technology, and they could play a crucial role in building drought resilience of the farmers in the EGP.

Three models of SPIPs are in operation in the Ganges basin: community-owned, individual-owned, and entrepreneur. In a community-owned model, a group of farmers share the SPIP, and it may be beneficial for farmers in Bihar and Nepal Terai where the majority are small and marginal farmers. Well-off farmers who can afford the SPIP and have installed them use an individually owned model. The third is the entrepreneur model, in which solar-run pumps are installed by one or more individuals to sell water to farmers.

When promoting solar for irrigation, policy makers must consider government spending and economic viability of deployment, and they should seek strategies that take care of the interests of all parties. The high capital cost of the technology is the biggest barrier to its adoption. But the limited consideration of farmers' perspectives on solar pumps could also be one of the key reasons for the limited uptake of SPIPs under government programs. Therefore, the focus could be on awareness generation and technology demonstration through engaging with the channels that are already reaching out to the farmers, including both state and non-state stakeholders.

As part of any promotion of SPIPS, governments must consider and manage the risk of the overextraction of groundwater. Furthermore, in the EGP, given the known incidence of groundwater contamination in the region, the quality of groundwater must be properly understood, including the influence of both geogenic and anthropogenic contaminants.

NOTE

1. International Water Management Institute (IWMI), Kathmandu, Nepal.

REFERENCES

Aggarwal, P. K., P. K. Joshi, J. S. I. Ingram, and R. K. Gupta. 2004. "Adapting Food Systems of the Indo-Gangetic Plains to Global Environmental Change: Key Information Needs to Improve Policy Formulation." *Environmental Science and Policy* 7 (6): 487–498.

Agrawal, S., and A. Jain. 2018. *Financing Solar for Irrigation in India: Risks, Challenges and Solutions.* New Delhi, India: Council on Energy, Environment and Water (CEEW).

Anonymous. 2015. *Solar Powered Pumps for Irrigation Purposes (SPIP)*. Kathmandu, Nepal: ICIMOD.

Bastakoti, R., F. Sugden, M. Raut, and S. Shrestha. 2017. "Key Constraints and Collective Action Challenges for Groundwater Governance in the Eastern Gangetic Plains." In *Water and Collective Action—Global Multi-scale Governance Challenges*, edited by D. Suhardiman, A. Nicol, and E. Mapedza. pp.131-142. Oxon, UK. Earthscan.

Bastakoti, R. C., L. Bharati, U. Bhattarai, and S. M. Wahid. 2017. "Agriculture under Changing Climate Conditions and Adaptation Options in the Koshi Basin." *Climate and Development* 9 (7): 634–648.

Blunck, M. 2013. *Potential and Challenges for Solar Irrigation in Bihar*. New Delhi: IGEN (Indo-German Energy Programme).

Dhawan, V. 2017. "Water and Agriculture in India." Background paper for the South Asia expert panel during the Global Forum for Food and Agriculture (GFFA). Hamburg. https://www.oav.de/fileadmin/user_upload/5_Publikationen/5_Studien/170118_Study_Water_Agriculture_India.pdf

Dhital, R. P. 2015. *Government Policies for Solar Pumps (Drinking and Irrigation in Nepal)*. Kathmandu, Nepal: AEPC (Alternative Energy Promotion Center).

Ghose, N. 2015. *Solar Pumps for Irrigation: GIZ's Work in Bihar*. New Delhi: IGEN (Indo-German Energy Programme).

Hartung, H., and L. Pluschke. 2018. *The Benefits and Risks of Solar-Powered Irrigation—A Global Review*. Rome, Italy. FAO (Food and Agriculture Organization of the United Nations) and GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit).

Jain, A., and T. Shahidi. 2018. *Adopting Solar for Irrigation: Farmers' Perspectives from Uttar Pradesh*. New Delhi, India: Council on Energy, Environment and Water (CEEW).

Jain, S. K., B. R. Sharma, A. Zahid, M. Jin, J. L. Shrestha, V. Kumar, S. P. Rai, J. Hu, Y. Luo, and D. Sharma. 2009. "A Comparative Analysis of the Hydrogeology of the Indus-Gangetic and Yellow River Basins." In *Groundwater Governance in the Indo-Gangetic and Yellow River Basins*, edited by A. Mukherji, K. G. Villholth, B. R. Sharma, and J. Wang. pp.43-64. London, UK CRC Press, Taylor Francis Group.

Kumar, D., A. Singh, R. K. Jha, S. K. Sahoo, and V. Jha. 2018. "Using Spatial Statistics to Identify the Uranium Hotspot in Groundwater in the Mid-Eastern Gangetic Plain, India." *Environmental Earth Sciences* 77 (19): 702.

Kunen, E., B. Pandey, R. Foster, J. Holthaus, B. Shrestha, and B. Ngetich. 2015. *Solar Water Pumping: Kenya and Nepal Market Acceleration*. In conference proceedings of Solar World Congress 2015, Daegu, Korea, November 8–12. http://proceedings.ises.org/paper/swc2015/swc2015-0175-Pandey.pdf.

Li, X., S. R. Waddington, J. Dixon, A. K. Joshi, and M. C. de Vicente. 2011. "The Relative Importance of Drought and Other Water-Related Constraints for Major Food Crops in South Asian Farming Systems." *Food Security* 3 (1): 19–33.

MIT (Massachusetts Institute of Technology). 2017. "MIT Researchers Release Evaluation of Solar Pumps for Irrigation and Salt Mining in India." *MIT News*, November 13. http://news.mit.edu/2017/mit-researchers-release-evaluation-solar-pumps-used-irrigation-and-salt-mining-india-1113.

MNRE (Ministry of New and Renewable Energy). 2017. *Annual Report 2016–2017*. MNRE. New Delhi. https://mnre.gov.in/file-manager/annual-report/2016-2017/EN/pdf/4.pdf.

Moors, E. J., A. Groot, H. Biemans, C. T. van Scheltinga, C. Siderius, M. Stoffel, C. Huggel, et al. 2011. "Adaptation to Changing Water Resources in the Ganges Basin, Northern India." *Environmental Science and Policy* 14 (7): 758–769.

Mukherjee, I., and U. K. Singh. 2018. "Groundwater Fluoride Contamination, Probable Release, and Containment Mechanisms: A Review on Indian Context." *Environmental Geochemistry and Health* 40 (6): 2259–2301.

Mukherji, A., and T. Shah. 2005. "Groundwater Socio-ecology and Governance: A Review of Institutions and Policies in Selected Countries." *Hydrogeology Journal* 13 (1): 328–345.

Namara, R. E., R. K. Nagar, and B. Upadhyay. 2007. "Economics, Adoption Determinants, and Impacts of Micro-Irrigation Technologies: Empirical Results from India." *Irrigation Science* 25 (3): 283–297.

Paul-Bossuet, A. 2017. *Can Solar Pumps Give Nepal's Women Farmers a Brighter Future? Thomas Reuters Foundation News*, March 21.

Rai, U. 2018. "Chasing the Sun in Samastipur, Delhi." *The Hindu Business Line*, March 9. https://www.thehindubusinessline.com/specials/india-interior/solar-powered-irrigation-in-bihars-samastipur-helping-farmers/article23005940.ece.

Rajmohan, N., and S. A. Prathapar. 2013. "Hydrogeology of the Eastern Ganges Basin: An Overview." IWMI Working Paper 157, International Water Management Institute, Colombo, Sri Lanka.

Raymond, A., and A. Jain. 2018. *Solar for Irrigation: A Comparative Assessment of Deployment Strategies*. New Delhi, India: Council on Energy, Environment and Water (CEEW).

Renewable World. 2018. 10-year impact report. London. Renewable World. https://renewable-world.org/app/uploads/2018/12/RW-Impact-Report-WEB.pdf

Rijsberman, F. 2003. "Can Development of Water Resources Reduce Poverty?" *Water Policy* 5 (5-6): 399-412.

Saha, D., and S. Sahu. 2016. "A Decade of Investigations on Groundwater Arsenic Contamination in Middle Ganga Plain, India." *Environmental Geochemistry and Health* 38 (2): 315–337.

Saha, D., A. Zahid, S. R. Shrestha, and P. Pavelic. 2016. "Groundwater Resources." In *The Ganges River Basin: Status and Challenges in Water, Environment and Livelihoods*, edited by L. Bharati, B. R. Sharma, and V. Smakhtin, 24–51. Oxon, U.K.: Routledge—Earthscan.

Schmalensee, R. 2015. "The Future of Solar Energy: A Personal Assessment." *Energy Economics* 52 (1): 142–148.

Shah, T. 2009. *Taming the Anarchy: Groundwater Governance in South Asia*. Washington, DC: Resources for the Future Press.

Shah, T., S. Bhatt, R. K. Shah, and J. Talati. 2008. "Groundwater Governance through Electricity Supply Management: Assessing an Innovative Intervention in Gujarat, Western India." *Agricultural Water Management* 95 (11): 1233–1242.

Shah, T., A. Deb, A. Roy, A. S. Qureshi, and J. Wang. 2003. "Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence." *Natural Resources Forum* 27 (2): 130–141.

Shah, T., N. Durga, G. P. Rai, S. Verma, and R. Rathod. 2017. "Promoting Solar Power as a Remunerative Crop." *Economic and Political Weekly* 52 (45): 14–19.

Soman, P., A. Verma, and A. Harley. (n.d.) "Using Solar Power and Drip Irrigation Pumps (SPIP) to Improve Livelihoods for Vulnerable Women Farmers in Bihar, Gaya." Project Report, ICIMOD. Kathmandu, Nepal. http://www.icimod.org/resource/17197.

Sugden, F., N. Maskey, F. Clement, V. Ramesh, A. Philip, and A. Rai. 2014. "Agrarian Stress and Climate Change in the Eastern Gangetic Plains: Gendered Vulnerability in a Stratified Social Formation." *Global Environmental Change* 29: 258–269.

UNDP (United Nations Development Programme). 2016. *Renewable Energy for Rural Livelihood Program*. Kathmandu, Nepal: UNDP.

Connect with the Water Global Practice

www.worldbank.org/water   worldbankwater@worldbank.org   @worldbankwater   blogs.worldbank.org/water

WORLD BANK GROUP

SAWI SOUTH ASIA WATER INITIATIVE

GWSP GLOBAL WATER SECURITY & SANITATION PARTNERSHIP

SKU W19070