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CSISA Research Note 15

Costs of diesel pump irrigation systems in the Eastern Indo-Gangetic Plains: What options exist for efficiency gains?

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Introduction

Groundwater irrigation plays a critical role in supporting food security, rural livelihoods and economic development in South Asia. Yet, large disparities in groundwater access and use remain across the region. In the Western Indo-Gangetic Plains (WIGP) of India and Pakistan, subsidized rural electrification and fuel for groundwater pumping has enabled significant growth in agricultural productivity over recent decades (Shah 2007). In many areas, groundwater development has however also contributed to over-extraction and aquifer depletion, especially in the WIGP (MacDonald et al. 2016; Mukherjee et el., 2017). In contrast, groundwater resources in the Eastern Indo-Gangetic Plains (EIGP) of Nepal and eastern India remain under-exploited; current aggregated rates and areas of irrigation also appear to be only a fraction of estimated development potential (Saha et al., 2016). This limits farmers' ability to grow crops outside the monsoon season, or to manage risks posed by rainfall variability and dry spells within the monsoon – both of which contribute to low productivity and rural poverty.

A barrier to expansion of groundwater irrigation in Nepal's Terai region is the dependence of farmers on expensive, unsubsidized diesel or petrol power for irrigation pumping. At present, diesel pumps account for over 80% of installed irrigation pump horsepower in the EIGP (Shah et al., 2006). Proposals by governments, donors and researchers to address economic barriers to groundwater access include the expansion of rural electrification or introduction of renewable-based (e.g. solar) pumping technologies that reduce or eliminate the comparatively high costs of diesel fuel (Mukherji et al., 2017; Shah et al, 2018). While desirable in many ways, solar irrigation systems nonetheless face a number of technical and financial scaling challenges in the EIGP (Hartung & Pluschke, 2018). These include high up-front capital costs, limited availability of maintenance services, and risk of accelerated and excessive withdrawal where pumping costs are significantly reduced and regulation is weak (Closas & Rap, 2017). Similarly, while access to reliable electricity supplies through direct grid connections are increasing in many parts of the EIGP (Mukherji et al., 2018), rural electrification for irrigation is likely to require considerable investments in infrastructure and may take decades to deliver at scale. As such, policies and development initiatives that focus exclusively on electrification or solar pumping fail to seize opportunities for near-term gains in water availability that could positively affect farm production, income generation, and food security in the EIGP.

The Cereal Systems Initiative for South Asia (CSISA) is a regional initiative to sustainably increase the productivity of cereal-based cropping systems, thus improving food security and farmers' livelihoods in Bangladesh, India and Nepal. CSISA works with public and private partners to support the widespread adoption of resource-conserving and climate-resilient farming technologies and practices. The initiative is led by the International Maize and Wheat Improvement Center (CIMMYT), implemented jointly with the International Food Policy Research Institute (IFPRI) and the International Rice Research Institute (IRRI), and is funded by the US Agency for International Development (USAID) and the Bill & Melinda Gates Foundation.

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Addressing sub-optimal performance of existing diesel-pump irrigation systems offers an alternative for delivering quick improvements in the affordability of groundwater irrigation in the EIGP, while also complementing and supporting future transition to alternative technologies including solar. Anecdotal evidence indicates that many diesel-pump irrigation systems in the EIGP operate at very low fuel to water delivery efficiencies (Bom et al., 2001; Shah, 2009), suggesting that scope may exist to improve pump performance and reduce irrigation costs for smallholder farmers. However, to date, there has been little systematic research to quantify the magnitude and underlying causes of variability in groundwater access and pumping costs in the EIGP, or the resulting impacts on farmer irrigation practices and livelihoods. This is a first-step in addressing this knowledge gap and identifies potential opportunities to reduce groundwater access costs in existing diesel-pump irrigation systems in the EIGP.

Methodology

Data were collected in two districts in the mid-western Terai of Nepal – Rupandehi and Kapilbastu districts. These two districts were selected as they represent areas where groundwater is the main source of water supply for most farmers and diesel-pump irrigation systems are widespread due to limited rural electrification. These locations are therefore in many ways comparable with characteristics of smallholder agriculture across the EIGP. Furthermore, Rupandehi and Kapilbastu districts are also heterogeneous with respect to the socio-economic status of farming communities and underlying aquifer characteristics, both of which we hypothesize may be drivers of heterogeneous groundwater access and irrigation costs within the EIGP.

To evaluate heterogeneity in groundwater access costs and their impacts on agricultural practices, we conducted a structured survey of 434 households who reported using groundwater for irrigation in a total of 33 villages (Figure 1).

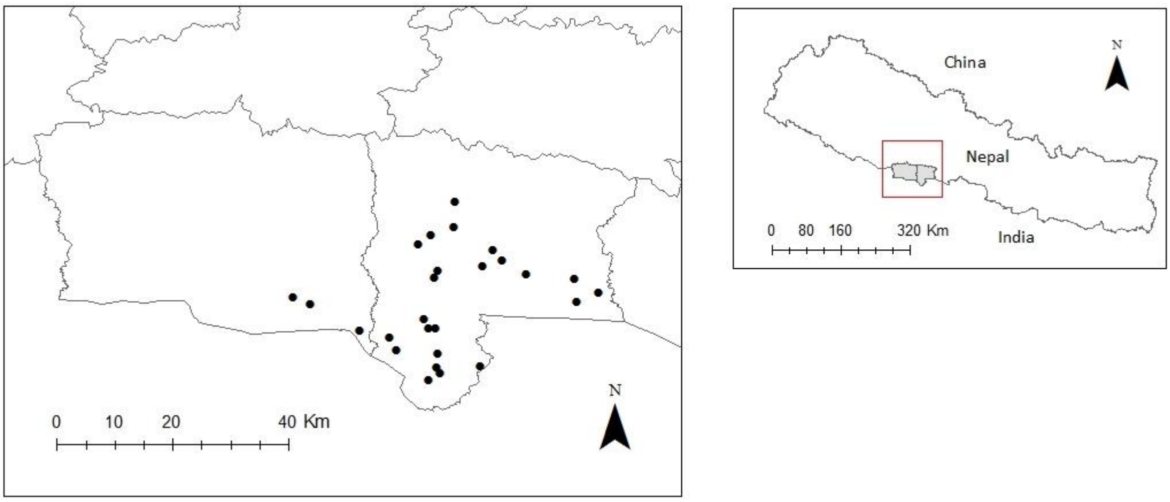

Figure 1. Location of surveyed villages in Kapilbastu and Rupandehi districts (left) in Nepal (right).

Villages were initially selected randomly from national census lists; this sample was subsequently refined through field investigations to ensure groundwater resources were accessible and that groundwater provided the main source of irrigation supply.

In each village, between 12 and 16 farmer households were selected randomly for survey. Farmers were asked to provide information about household demographics, livelihood strategies, assets, and agricultural production and input use decisions in the past year. Detailed questions were asked about irrigation practices, including the (i) types and characteristics of systems – borewells and pumpsets – used to access groundwater for irrigation, and (ii) the frequency, duration and cost of irrigation events per crop and season on the household's largest plot. For the latter we selected the largest irrigated plot as the unit of survey discussion and data analysis. This is because this plot typically represents farmers' greatest expenditure on irrigation. It also provides a consistent comparison for assessing irrigation access costs and their impacts on agricultural production across households. Alongside information for the largest plot, we also collected information about the total irrigation cost per season across all of the plots managed by farmers to analyze the proportion of irrigation costs to whole farm costs.

Initial Results:

Landholding and irrigation system characteristics

Our survey focused on households where agriculture was the primary occupation and groundwater provided the main source of water for irrigation. The average cultivated land area per household was 0.95 hectares, often comprised of multiple plots, with 67% of households (*n* = 292) cultivating less than 1 ha. Significant land fragmentation was observed – consistent with evidence about farm sizes and landholding structures in the Terai – with each household cultivating an average of 5.6 plots with a typical plot size of 0.20 hectares.

Figure 2. Two examples of Chinese-made pumpsets using variations on popular Indian brand names (Kirloskar and Fieldmarshal)

Of the farmers in our sample, 76% irrigated their plots using their own pumpsets. The remainder relied on rented pumpsets. Farmers renting pumpsets had smaller land holdings (0.43 vs 0.99 hectares for owners) and cultivated smaller land areas (0.50 vs 1.10 hectares for owners). Renters also received lower levels of financial support from off-farm work or remittances – potentially indicative of greater financial constraints to investment in irrigation technologies. On average, each household utilized a total of 1.1 pumpsets for irrigation across all plots, with 99% of households using two or less owned or rented pumpsets for irrigation in the past year. In contrast, farmers accessed on average a total of 2.4 borewells for irrigation. Renting and sharing of borewells was also widespread; 72% of borewells reported were rented, and 81% of households rented at least one borewell for irrigation.

Indian pumpsets – almost all of which are operated using diesel – account for 61% of pumpsets reported, with Chinese pumpsets – typically operated using petrol, kerosene and/or diesel fuel – accounting for 39% of pumpsets (Table 1). Farmers erroneously reported a significant proportion of Chinese pumpsets as being Indian-made (around 17% of all pumpsets reported originally as Indian), with widespread prevalence of false or misleading branding (Figure 2) indicative of a lack of reliable information for farmers when making

decisions about pumpset investment. Indian pumpsets typically had a higher horsepower than Chinese pumpsets (5.3 vs 4.9 HP) and considerably larger investment costs (NPR 30,000 vs 19,000). However, Chinese pumpsets exhibited lower reliability, as evidenced by higher reported frequencies of repairs (0.38 per year of operation vs 0.25 for Indian pumpsets).

Table 1. Characteristics of irrigation pumpsets used by farmers

Pump type	Fuel source	*n*	Pump horsepower Mean (SD)	Cost of pump Mean (SD)	Annual pump repairs Mean (SD)
Chinese	Diesel	137	4.5 (0.6)	20,000 (6,500)	0.46 (0.54)
	Kerosene	42	5.9 (1.1)	18,000 (12,000)	0.16 (0.28)
	Petrol	6	6.5 (0.0)	15,000 (4,100)	0.0 (0.0)
	Total	185	4.9 (1.0)	19,000 (8,100)	0.38 (0.51)
Indian	Diesel	259	5.6 (1.3)	31,000 (9,900)	0.29 (0.51)
	Kerosene	2	3.1 (0.5)	31,000 (8,500)	0.28 (0.04)
	Total	261	5.3 (1.7)	30,000 (10,000)	0.25 (0.46)

Heterogeneity in costs of groundwater irrigation

Focusing on data related to the 2018 monsoon season – during which almost all farmers (379/434) in our sample grew rice irrigated with a diesel, petrol or kerosene pumpset on their largest plot – we observed large farmer-to-farmer variability in the cost of groundwater irrigation. The cost to fully irrigate one hectare of land was on average NPR 3,425 for surveyed farmers, with a range from NPR 500 to NPR 22,489 between households (Figure 3).

One of the major drivers of variable irrigation costs observed in Figure 3 appears to be pumpset ownership. Renters of pumpsets pay on average 184 NPR/hour to access a pumpset excluding embedded costs of fuel, which are equal to 100 NPR/hour on average given reported fuel prices and consumption rates. However, local variability in rental rates also exists. High market prices reaching as much as 400 NPR/hour (excluding fuel) were observed in some villages, while in others pumpsets were shared free of charge as long as the renting farmer provided their own fuel for running the pumpset. Notably, farmers typically do not pay any fee for renting a borewell. Only 2.7% (7/257) of borewells rented for irrigation in our sample incurred a cost to the renting farmer, with an average price paid of 92.9 NPR/hour paid on the few occasions when a fee was levied.

Alongside pumpset ownership, differences in the fuel use efficiency of pumpsets also contribute to variability in groundwater irrigation costs. Indian pumpsets have significantly ($p<0.001$) higher reported average fuel consumption rates (0.95 litres/hour) compared with Chinese pumpsets (0.80 litres/hour). Fuel consumption rates increased with horsepower for both categories of pumpsets, with the largest rates of fuel consumption – sometimes in excess of 2 litres/hour – typically found for large (6+ HP) Indian pumpsets (Table 2). Importantly, switching from a large (> 5 HP) Indian pumpset to a smaller (≤ 5 HP) Chinese pumpset equates to an average fuel consumption saving of 0.39 litres/hour – equivalent to 991 NPR/irrigation/ha (a 29% reduction) given reported average irrigation times, plot sizes and fuel costs for paddy production in the last monsoon season.

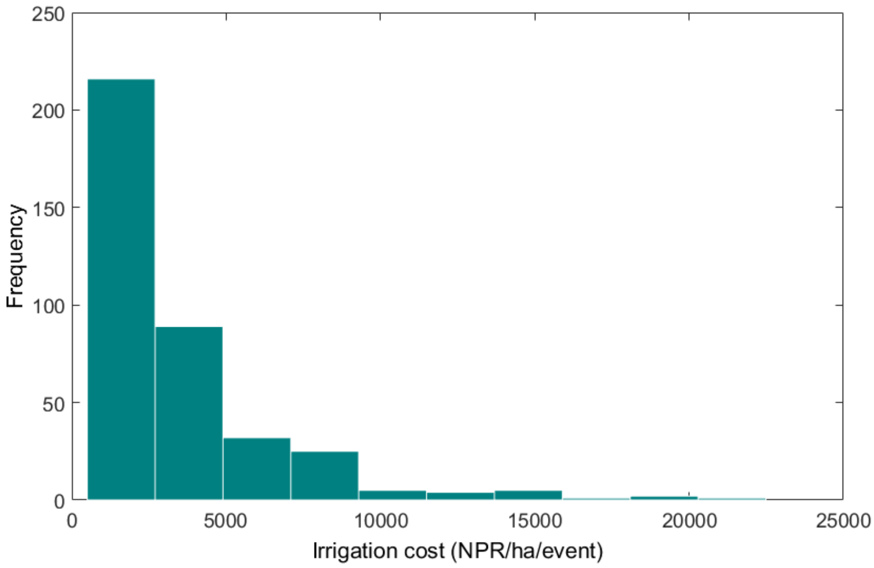

Figure 3. Distribution of irrigation costs (NPR per hectare per irrigation event) across surveyed farmer households for paddy grown in the last monsoon season.

Finally, differences in the time required by each farmer to irrigate their plots contribute a further large additional source of heterogeneity irrigation costs for farmers. The time required for a single irrigation of paddy on one hectare in the 2018 monsoon season ranged between 6 and 60 hours, with an average irrigation time of 25.4 hours. Causes of heterogeneity in irrigation time requirements are likely to be multifaceted, and may include local differences in borewell yields, spatial variability in rainfall and stages of crop growth, soil types or drainage class, plot size or distance from borewell used for irrigation, along with individual level variability in farmers' irrigation management practices and crop water demand. Analysis is ongoing to determine the key underlying drivers and determinants for irrigation event duration in order to understand potential opportunities for reducing irrigation costs through more efficient water management practices. However, it is clear that higher irrigation times can play an important role in magnifying existing differences in variable irrigation costs, in particular those related by rental fees or fuel efficiency of pumping systems, with important implications for equitable access to irrigation among smallholder farmers.

Table 2. Fuel consumption rates of irrigation pumpsets used by farmers to irrigate their largest plot in the last monsoon season

Pump type	***Pump horsepower***	***n***	***Fuel consumption (Litres/hour) Mean (SD)***
Chinese	≤ 5	113	0.76 (0.20)
	> 5	53	0.89 (0.17)
		166	0.80 (0.20)
Indian	≤ 5	150	0.86 (0.20)
	> 5	63	1.15 (0.23)
		213	0.95 (0.25)

Impacts of access costs on irrigation management practices

Farmers with higher irrigation costs – whatever their underlying causes – may choose or be forced to reduce use of irrigation inputs, resulting in greater exposure to drought risks and lower agricultural productivity. To evaluate impacts of variable costs observed in our sample on farmer irrigation management practices, Figure 4 displays the average costs to irrigate one hectare of paddy subdivided by the number of times farmers reported irrigating paddy during the last monsoon season on their largest plot.

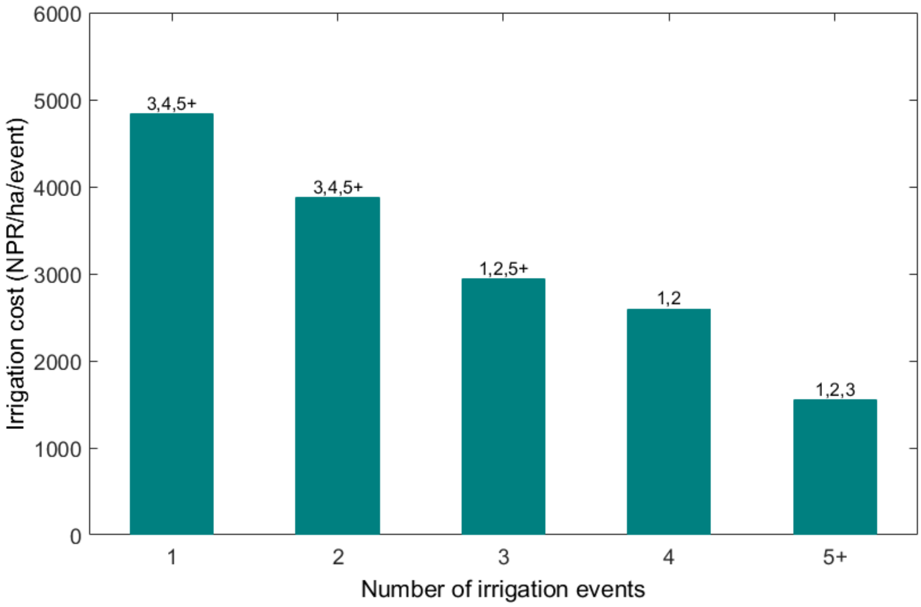

Figure 4. Average cost (NPR) to irrigate one hectare of paddy for farmers subdivided by the number of irrigation events in the last monsoon season on their largest plot. Numbers on the top of each bar denote statistically significant ($p<0.01$) differences between mean irrigation costs between different pairs of groups.

Our results show a clear downward trend – farmers with the highest irrigation costs on average irrigate paddy crops less frequently than those with lower irrigation costs. In general, differences in average irrigation costs for alternative frequencies are statistically significant ($p<0.01$) in particular across high and low frequency irrigators. However, it is important to recognize that irrigation costs are also highly variable between farmers irrigating at the same frequency, highlighting the importance of individual behavior in determining decisions around irrigation water use alongside economic costs. Further analysis is also needed to control for other confounding drivers of irrigation decisions, such as soil type/drainage class, and to determine measurable impacts on crop yields and incomes of reduced irrigation frequencies.

Research and Policy Implications

High costs of accessing groundwater for irrigation currently limit the ability of smallholder farmers in the EIGP – including the Terai of Nepal – to intensify agricultural production and reliably buffer crops against production risks, such as drought and monsoon rainfall variability (Kishore et al., 2014; Jain et al., 2017). Our preliminary findings demonstrate that opportunities exist to significantly reduce the variable costs of groundwater irrigation within existing diesel-pump systems, which if implemented could support rapid, near-term improvements in agricultural productivity, intensity and livelihoods. We discuss these issues in steps below, beginning with targeted subsidy programs, more energy-efficient pumping, reduced irrigation costs, and solar pumps.

First, given the wide disparity in groundwater access costs between pumpset owners and renters, key priorities for irrigation development policy could include interventions that improve access to pumping equipment for marginalized farmer groups. In Nepal, current government programs focus primarily on subsidizing the cost of borewell drilling (ADB, 2012). Our preliminary analysis however suggests that this is not a key driver of high costs of accessing groundwater for irrigation. Support should instead be targeted explicitly towards improving rates of pumpset ownership amongst small and marginalized farmer households, who currently are disproportionality dependent on rental markets for accessing groundwater and thus face the largest costs to access water for irrigation. Without support for accessing pumpsets, smallholders are likely to struggle to invest in productivity enhancing and risk-reducing irrigation technologies, and are unlikely to benefit from improvements in the performance of existing pumpsets – especially larger equipment – due to somewhat unique and oligopolistic nature of local water markets in the Terai. Irrigation in other countries in South Asia is highly subsidized through direct and indirect mechanisms (Shah et al., 2006). The overall costs of and unsustainability of subsidies are however a concern; well-designed programs should therefore phase out support mechanisms over time as smallholder farmers are increasingly able to access irrigation services and the private sector develops more affordable pumpset solutions.

Our analysis also indicates that reductions in irrigation access costs could also be achieved through promotion and support for farmers to adopt more fuel-efficient pumpset technologies and irrigation management practices. For example, smaller horsepower Chinese-made pumpsets consume less fuel than larger Indian pumpsets that appear to be preferred by farmers. Yet, despite Chinese pumpsets also being less costly and relatively easy to repair, our survey results indicate that the majority of smallholders continue to favor less fuel-efficient and unnecessarily large Indian pumpsets. Anecdotal evidence gathered through interactions and interviews with farmers in our study region and the Terai more broadly suggest that these decisions are driven by perceptions that Indian-made pumps have greater robustness, along with advice given by agricultural machinery dealers who are motivated to suggest larger horsepower pumpsets as a sales strategy to maximize sales profits on a per-unit basis.

These findings highlight the need for greater education of farmers about fuel efficient pumpset selection supported by data from *in-situ* pump testing, along with broader improvements in quality control and provision of maintenance services for imported Chinese pumpsets that currently constrain potential technological benefits. Improvements in the affordability and performance of existing diesel-pump irrigation systems could also help to support future transitions to use of alternative energy sources (e.g. solar) by increasing farmers' capacity to invest in these emerging, but still expensive, technologies. However, long-term shifts to renewable pump technologies must also consider risks to groundwater sustainability posed by large reductions in the variable cost of irrigation pumping (Closas & Rap, 2017; Urfels et al., 2019). While groundwater resources appear to be underexploited in the EIGP, aggregate regional statistics may mask significant spatial heterogeneity in aquifer conditions that could locally limit sustainable extraction potential. For example, farmers in some villages included in our survey reported challenges in accessing reliable groundwater supplies at shallow depths, in particular during the dry season when borewell yields were sometimes insufficient to enable farmers to irrigate landholdings fully. These findings are consistent with broader evidence of large local-level variability in shallow groundwater availability and resilience to abstraction across the IGP (van Dijk et al., 2016), and warrant further attention in the Terai when assessing future potential for intensification and extensification of groundwater irrigation.

Alongside these hydrologic constraints, our survey also highlights that capacity to scale renewable energy technologies such as solar irrigation may also be affected by some of the unique socio-organizational and economic characteristics of agricultural systems in the Terai and wider EIGP. Given high levels of existing land fragmentation in our study area and the region more broadly, development of portable high-capacity solar pumpsets that mimic existing lightweight and moveable pumpsets are a key need to support scaling of these technologies. Current state-of-the-art portable solar products are heavier, more expensive and deliver significantly lower water output than existing low-cost Chinese diesel or petrol pumpsets (Durga et al., 2016). Although increased demand may over time drive down costs, in this context, fossil fuel pumping systems are likely to remain the workhorse of irrigated cereal systems in the EIGP in the coming decades, highlighting the value of efforts to reduce inefficiencies these systems alongside ongoing advances to renewable pumping technologies.

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