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Energy supply and the expansion of groundwater irrigation in the Indus-Ganges Basin

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ABSTRACT
Irrigation using groundwater has expanded rapidly in South Asia since the inception of the Green Revolution in the 1970s. Groundwater currently represents the largest source of irrigation in the Indus-Ganges Basin (IGB), which feeds over one billion people and provides direct livelihoods for hundreds of millions of farmers. Although abundant in absolute terms, groundwater is overexploited in the western IGB plains and is underutilized in the east. The spatial and temporal patterns of groundwater development are the result of multiple demand factors: (a) farmer investment, (b) subsidies and markets, and (c) population density; as well as supply factors: (d) sources of groundwater recharge, and (e) energy supply and pricing. This paper examines trends in electricity supply and groundwater development in the Indian portion of the IGB over the 1980 – 1999 period, with contextual reference to groundwater irrigation in Pakistan, Nepal, and Bangladesh. Principal findings include early-1980s' growth in numbers of electric pumps across the Indian IGB followed by 1990s' stagnation in the eastern part of the basin; this trend is linked to electricity supply and pricing policies, which have varied markedly from state to state. The eastern IGB presents an energy-groundwater paradox: a region rich in energy sources but with inadequate electricity supply that has led to increased reliance on diesel power, which in turn is limiting development of groundwater – one of this region's most abundant and agriculturally productive resources.

Keywords: Groundwater; energy supply; subsidies; northern India.

1 Introduction

Throughout South Asia, the area of irrigated cropland using groundwater has expanded rapidly with the diffusion of Green Revolution technology (Dhawan, 1989). In India over the 1960–99 period, irrigation from tubewells and other wells grew by a factor of over four and currently represents well over half of the country's irrigated area (GOI, 2003; see Figure 1). Groundwater development occurred early during this period in north India, but the most rapid expansion, albeit from the lowest base, has taken place in the eastern states (Deb Roy and Shah, 2003; CMIE, 2003). Irrigated agriculture in the region increasingly depends on groundwater obtained by very large numbers of small pumps – millions in the Indus-Ganges Basin (IGB) alone (Shah, 2009). In this region of high population density, groundwater sustains crucially important food production and livelihoods. A cubic meter of groundwater produces more output and value, and is more easily traded, than a similar volume from canals or other sources. Despite the welfare benefits generated (Moench, 2003), rapid development of groundwater resources is becoming a major concern in the western IGB (Pakistan and the Indian states of Punjab, Haryana, and Uttar Pradesh), as it has led to declining water levels and increasing salinity (Dhawan, 1995), in addition to other water quality problems. At the same time, the eastern IGB (Bangladesh, Nepal Terai, and the Indian states of West Bengal and Bihar) has witnessed chronic under-utilization of available groundwater resources despite an abundance of water resources, fertile land, and labor. Here, skewed land tenure, farmers' limited access to markets (Kishore, 2004), and, we will argue, inadequate power supply, have limited the expansion of groundwater irrigation.

Policy options for the direct management of groundwater – whether on the one hand attempting to check overexploitation in the western IGB through regulatory controls such as volumetric caps, a permit system, or recharge programs (Sikka, 2002), or on the other hand to stimulate groundwater utilization in the eastern IGB through public tubewell development – are unlikely to make a significant impact. The large numbers of groundwater users stymie the effective enforcement of any regulatory measures in rural areas. Efforts to squeeze credit flows for investing in well development in regions of overexploited groundwater, as attempted by India's National Bank for Agriculture and Rural Development (NABARD), have limited impact because alternative credit from informal sources is readily available (Kurien, 2006). Moreover, this would at best control development of additional wells; extraction from existing wells would remain unaddressed.

In the eastern IGB, where government programs (e.g., Million Wells Scheme, see GOI, 2005) have sought to promote

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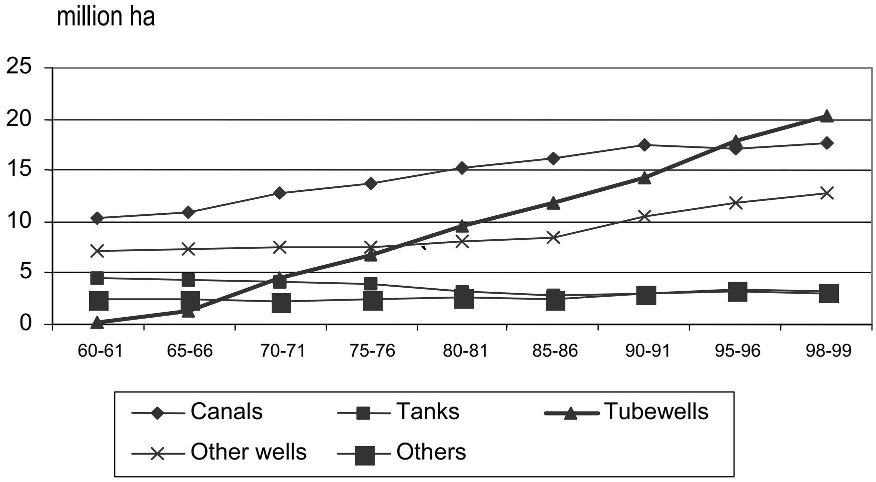

Figure 1 Irrigated area in India, 1960–99.
(*Source*: GOI, 2003).

groundwater development, the institutions for targeting investments, ensuring maintenance, and distributing welfare gains equitably have remained ineffective. On both ends of the continuum from management to development, groundwater irrigation hinges directly on energy delivery and offers considerable opportunity for co-management of the two resources (Shah *et al.*, 2003). As a result, we hypothesize that management of energy supply has been an important determinant of the patterns of groundwater development, and as such, continues to offer potentially effective policy options for groundwater management. Where electricity is the primary energy source, a combination of supply targeted to farmers' seasonal water (and thereby, energy) demands, pricing, and judicious management of the power infrastructure at the substation, feeder, and transformer levels could encourage sustainable groundwater practices and reinforce the power utilities' financial position. Most of the eastern IGB, however, has come to rely on diesel for groundwater pumping (Mukherji, 2006; Pant, 2004; Kishore, 2004). Here, aquifer conditions are better (shallow lifts), and spreading the welfare benefits of groundwater irrigation is more of an imperative than managing extraction. Appropriate pump technology and cost, combined with groundwater sharing mechanisms are important determinants of effective diesel energy use in these conditions.

The groundwater-energy nexus in the IGB is characterized by water scarcity with relative abundance of electricity supply in the western basin contrasted with water abundance and electricity scarcity in the eastern part. These patterns have been identified by Shah *et al.* (2006); for our purposes here, we refer to these east-west gradients as the '*water-energy divide.*' Against this backdrop, our analysis will address two questions that are central to the way the energy-groundwater nexus plays out in the IGB. First, how do energy type (electricity vs. diesel) and price influence groundwater development? And second, what are the energy-water co-management options for sustaining hundreds of millions of livelihoods in the IGB that are based directly or indirectly on groundwater irrigation? Our main point of departure is that improved understanding of the effects of energy supply and pricing on groundwater demand will facilitate the formulation of policy recommendations to support continued and improved livelihoods and economic benefits while ensuring the sustainability of both groundwater and energy resources.

2 Managing groundwater development

The IGB groundwater economy is large, not just in terms of area irrigated or volume pumped but also in terms of the population whose livelihoods directly depend on groundwater. The four IGB countries (Bangladesh, India, Nepal and Pakistan) pump 260 km^3 per year, the greatest volume of groundwater extraction in a single region (Shah, 2007). The IGB also has the world's greatest concentration of poverty: close to two-thirds of the combined population of 1 billion directly depend on groundwater and agriculture for their livelihood. In India, over 63% of the gross cropped area is irrigated by groundwater (GOI, 2003), and in the other three countries, the area irrigated by groundwater is increasing rapidly (Shah *et al.*, 2003a). Farmer investment in groundwater irrigation has led to the proliferation of water markets. Although there is nearly uniform consensus concerning the effect that water markets have had in extending groundwater irrigation, researchers and policy analysts continue to debate the functioning and equity impacts of markets (Pant, 1992; Dubash, 2002; and Fujita, 2004). Given the importance of groundwater in IGB economies, governments have implemented policies and programs to facilitate its development. Some of the means adopted to achieve this have been credit support for digging wells, investments in deep tubewells, subsidies on smaller pumps, and highly subsidized – in some states free – energy supply (Sinha *et al.*, 2006).

Consistent data across the four IGB countries are difficult to access. As a result, we focus on the Indian IGB, which spans the east-west water-energy divide. The growth in numbers of electric pumps in Indian IGB states is shown in Figure 2.

While Uttar Pradesh and Punjab show the most steady increase in the additional pumps added each year, the total additional pumps added in the Indian IGB region as a whole peaked in

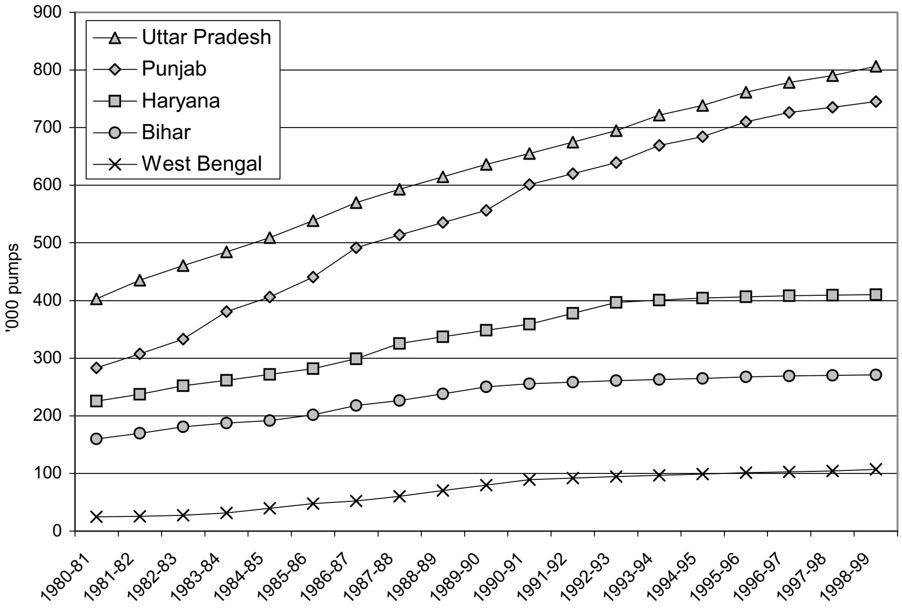

Figure 2 Growth in electric pumps in Indian IGB states.
(*Source*: CMIE, 2003).

1986–87. Several factors explain the growth in pump numbers. The 1980s witnessed ambitious government programs to promote private tubewells, supported by soft loans to farmers and rural electrification. Farmers across the IGB continued to adopt high-yielding varieties of cereal crops, initially wheat with moderate to high water demand, followed by rice with very high water demand. The rice-wheat rotation that is now the most prevalent cropping pattern in the IGB (covering more than 13.5 million ha, see Regmi *et al.*, 2002) resulted from a combination of high and assured procurement prices and subsidized inputs (not least energy for groundwater). Additionally, the general shift to a flat-rate electricity tariff for agricultural use in most states induced new entrants to the groundwater economy. Nevertheless, the eastern IGB, especially Bihar and West Bengal, was less able than the west to sustain growth through the 1990s in response to these initiatives. Growth in pump numbers stagnated in the early 1990s in the eastern IGB states, a process inextricably linked with the failure of state power utilities. Table 1 shows the percentage area sown, number of pumps per hectare of net sown area, and the compounded growth rate of pumps for the first decade, i.e., 1980–81 to 1988–89.

Table 1 Number of pumps per hectare of net sown area (NSA) in Indian IGB states.

State	NSA, 1988–89 (%)	No. of pumps/ ha NSA, 1988–89	Growth in no. of pumps, 1980–81 to 1988–89 (%/year)
Punjab	84.2	0.176	5.22
Haryana	82.6	0.112	3.20
UP	59.0	0.046	3.72
Bihar	42.9	0.036	2.82
West Bengal	62.6	0.019	7.99

(*Source*: CMIE, 2003).

Declines in groundwater levels are common in areas of the western IGB, particularly in those regions – mostly along the Himalayan mountain front – where saline groundwater does not represent an impediment to pumping (Dhawan, 2005; World Bank and GOI, 1998). In response, direct controls on groundwater through pumping restrictions have not been administratively or politically feasible, given the very large numbers of pump owners and water buyers. There is some cause for optimism in the emerging trends of farmer diversification away from cereal crops (with their high water demand), although the option of stimulating such cropping shifts as a matter of agricultural and food policy is fraught with difficulty, not least because food security in India – and the IGB in general – is firmly built on irrigated wheat and rice (Paroda, 2003; Rosegrant *et al.*, 2002). Additionally, as we have noted above, two-thirds of the IGB population makes a living from agriculture and represents a huge electoral base whose sense of entitlement is routinely upset by policy changes.

3 Implications of energy supply for groundwater management

Energy consumption by agriculture is a reflection of the pump density and usage by state in the Indian IGB and is shown in Figure 3. Punjab and Haryana have high pump densities, and the proportion of energy used in agriculture is also high. However, it is interesting to note that beginning in Uttar Pradesh and Bihar in the early 1990s, and followed by Punjab and Haryana in the mid 1990s, agriculture's share of total power supply began declining. In the eastern IGB, this was a result of conversion to diesel pump technology following the collapse of rural electrification. Farmers are understandably concerned about the productivity of their operations with higher-cost diesel (Mukherji, 2006). In the western IGB, the reduction in agricultural power share stemmed

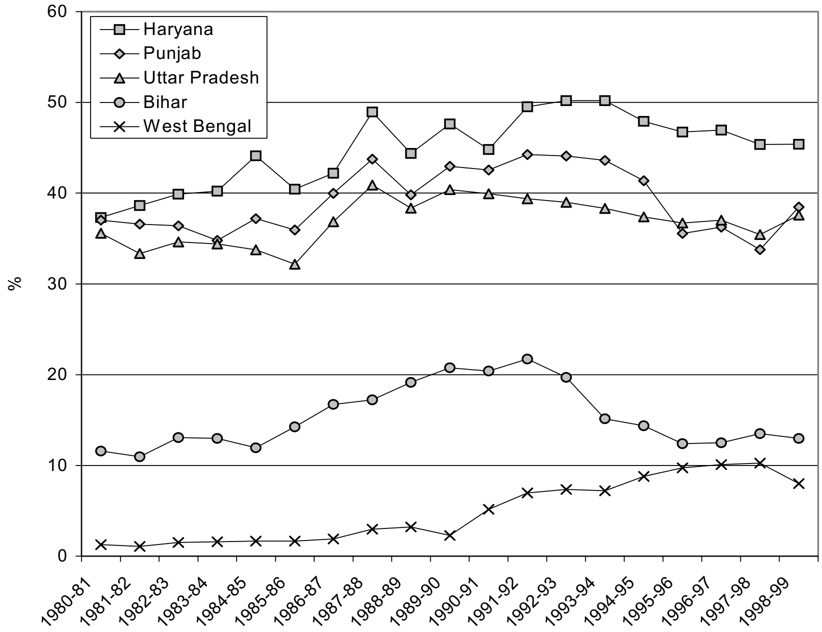

Figure 3 Agricultural share of total power supplied in Indian IGB states. (*Source*: CMIE, 2003).

more from reduced hours of supply, the only effective strategy available to the power utilities to redress rising financial deficits.

A critical feature of rural electrification and the increasing use of grid power to pump groundwater was the shift in Indian states from metered supply to flat-rate tariff (fixed monthly or annual charge per horsepower of pump capacity). In the aftermath of the 1970s' political upheaval that followed Prime Minister Indira Gandhi's imposition of emergency rule (characterized by extra-Constitutional powers), politicians began offering farmers subsidized flat-rate power, a process that proceeded on a state-by-state basis (Dubash and Rajan, 2001). The process began as early as 1977 in water-scarce states in southern and central India (Andhra Pradesh, Tamil Nadu, Maharashtra, and Tamil Nadu); by 1989, all agriculturally important states, with the exception of Punjab, had shifted to flat-rate supply. Despite disincentives placed by external (multilateral) donors, Punjab too acceded and switched to flat-rate supply in 1996. Further political manipulation saw the introduction of free power supply, first to poor, small farmers. However, once the floodgates were opened, it proved difficult to resist pressure and agitation by farmers. As a result, free power for agriculture became a political sop beginning in Tamil Nadu and Andhra Pradesh, and followed in the IGB by Punjab, whose chief minister has been one of the more strident advocates for free power to agriculture. The measure was ostensibly taken to avoid the costs of billing several million scattered groundwater irrigators who each typically consumed around $300 worth of energy annually. While reducing administrative costs, significant repercussions included indiscriminate pumping as well as a decline in the financial health of the state electricity boards.[1] Electricity regulatory commissions have been established, although these are not immune to political interests and have yet to demonstrate decisive control over energy supply and pricing (Dubash, 2006).

Most states show increases in energy used per pump (Figure 4). It is of particular interest to note that although West Bengal has low numbers of pumps and low pump density, the energy consumption per pump has shown a rapid increase, especially after 1989–90. This is primarily due to the fact that deep (large) tubewells are on electric supply, while shallow lift (smaller) wells are increasingly fitted with diesel pumps. An informal groundwater market in this state where large tubewell owning farmers sell water to smaller farmers has also been reported (Mukherji, 2006).

4 Conclusions

Notwithstanding the different conditions found in Pakistan, India, Nepal, and Bangladesh (Shah, 2009), we contend that coordinated energy and water management represents the most effective set of policy options to allow for sustainable use of groundwater, equitable access to water, improved rural livelihoods, and reversal of power utility fortunes in the IGB. Research on groundwater irrigation in China (Wang *et al*., 2007) and the energy-irrigation nexus in Mexico (Scott and Shah, 2004) supports this view. In northwest India and parts of Pakistan where electrical power predominates, power supply scheduling needs to be better matched to the demand for groundwater (Shah *et al*., 2003b). Based on the recognition that groundwater has surpassed canal irrigation and rainfed cropping in the IGB, public investment, particularly in the eastern IGB, should focus on improving and expanding the power grid and thus allow farmers' own investment along with water trading to increase access to irrigation using groundwater. Additionally, canal and groundwater conjunctive management regimes need to be explicitly addressed through improved canal irrigation operations. In the diesel-based groundwater regions of Bangladesh, Nepal Terai, and eastern India, improved pump

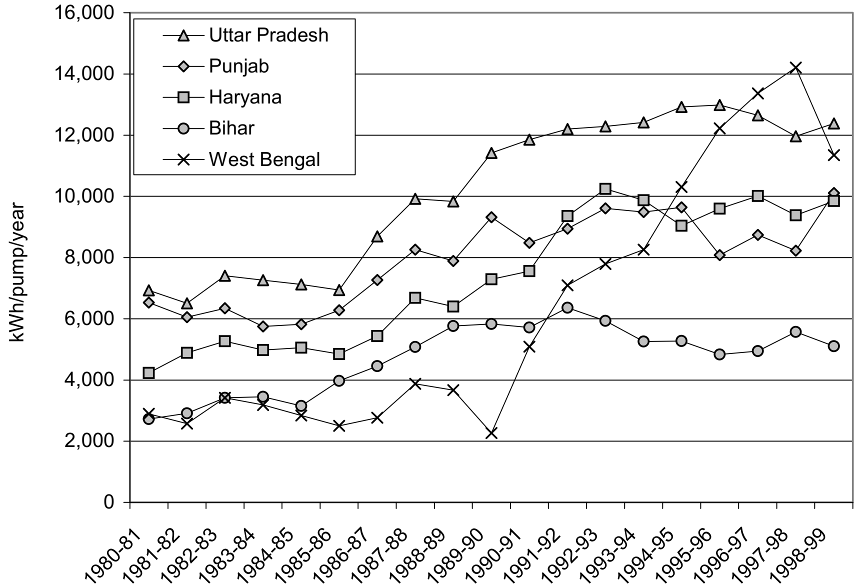

Figure 4 Unit power consumption per pump in Indian IGB states.
(*Source*: CMIE, 2003).

technology (smaller, portable, and fuel-efficient pumps), services, and after-sales support along with forward market linkages appear to offer the greatest potential for expanding the livelihood benefits of groundwater irrigation.

In the western IGB, progressive farmers operating consolidated holdings and hiring sufficient labor represent a potent political and social power bloc, and elected representatives will be challenged to curtail their sense of entitlement to free or flat-rate electricity. Alternatives do exist; the recently implemented Jyotirgram scheme rewired Gujarat state, separating agricultural power supply from rural households, small businesses, schools, etc. and led to improved customer satisfaction and power utility performance (Shah, 2007). On the other hand, stagnant agriculture, inadequate markets, declining wages, and chronically poor governance in parts of the east have created a diverse array of development challenges. It is thus unlikely that groundwater or the energy to pump it will emerge as central factors on which to build a popular or political groundswell. In providing an escape valve for social tension in eastern India, migration to western India and the reverse-direction remittance flows further buttress the east-west water-energy divide.

Ironically, coal-rich eastern India is the primary source of electrical power generation (CMIE, 2003), yet the benefits are being captured – both in agriculture and industry – outside this region. The interlinking of rivers may complete the separation of eastern India from its resources – now water, after energy and labor. Dynamic, groundwater-led agricultural growth, including positioning the eastern IGB to increase rice production for domestic and world markets, provides ample scope for regional development. To achieve this, the energy divide must be flipped from west to east through strategic investment in power supply infrastructure and institutional reform of the power sector (Dubash and Rajan, 2001). This may only take place when western IGB farmers find that water and financial constraints (particularly exerted through the power sector) make rice-wheat cropping less remunerative, hence causing them to diversify cropping patterns. At the same time, eastern IGB farmers have a clear opportunity to make better use of their region's abundant groundwater, fertile land, and productive labor resources.

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Note

[1] Flat rate or free power to agriculture alone, however, does not fully explain this trend.

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