WATER GLOBAL PRACTICE

Accelerating Irrigation Expansion in Sub-Saharan Africa

Policy Lessons from the Global Revolution in Farmer-Led Smallholder Irrigation

Tushaar Shah, Regassa Namara, and Abhishek Rajan

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Abbreviations

BADC	Bangladesh Agricultural Development Corporation
BMDA	Barind Multipurpose Development Authority
DTW	deep tubewell
FLSI	farmer-led smallholder irrigation
ha	hectare
HYV	high-yielding variety
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
km^3	cubic kilometer
Mha	million hectare
NGO	nongovernmental organization
RWH	rainwater harvesting
SCARP	Salinity Control and Reclamation Project
SIP	solar irrigation pump
STW	shallow tubewell

Chapter 1 Introduction

Sub-Saharan Africa urgently needs to accelerate the pace of agricultural growth to improve livelihoods, ensure food security, and keep droughts from turning into famines. However, this requires the region to increase smallholder irrigation faster than its current sluggish pace. In this respect, explosive growth since the 1970s in distributed farmer-led smallholder irrigation (FLSI) in China, South Asia, and elsewhere may offer Sub-Saharan Africa better guidance than state-led centralized large irrigation projects. Proactive policy support, prominence of market players, economies of scale and scope, village-level irrigation service markets, government incentives, and subsidies on motor pumps and boreholes have all triggered and fueled rapid expansion of motor pump-driven FLSI that made famines history and countries food-secure in Asia in a short span of a decade or two. With its ample shallow groundwater resources and sparse farming areas, Sub-Saharan Africa has immense potential to grow pump-driven FLSI quickly, cost-effectively, and without risking the environmental ill effects observed in Asia and elsewhere.

To realize this potential, Sub-Saharan African policy makers need to do five things: (a) shed excessive precaution; (b) proactively promote FLSI through government programs and support, (c) introduce smart incentives to make motor pumps and flexible pipes affordable, support pilots to demonstrate alternative FLSI technologies and institutional models; (d) liberalize imports of irrigation equipment; and (e) map, assess, and monitor water resource availability and demand. A “big push” to FLSI will work better than an incremental trickle because high-volume-low-margin FLSI growth generates economies of scale and scope, which are essential. Interventions by nongovernmental organizations (NGOs) are useful for demonstration and piloting innovations, but market players are best placed to achieve scale. Finally, Sub-Saharan Africa can and needs to leapfrog and build its FLSI economy around solar irrigation pumps, which are destined to disrupt FLSI globally in the years to come.

Irrigation and Smallholder Agriculture

Agriculture contributes, on average, 30 percent of gross domestic product and 67 percent of employment in Sub-Saharan Africa countries, and accelerating its growth has been a high priority in the region (FARA 2003). Some 80 percent of people in this region live in rural areas, and 70 percent depend on agriculture for their livelihoods (FARA 2003; Merrey and Sally 2008). A decade ago, some 204 million people were malnourished, one-third of whom were children (Merrey and Sally 2008, 515). The situation has not improved much since then: “The vital statistics of African agriculture are bleak: yields are on average a quarter of those in other parts of the world, soil fertility has declined and agricultural productivity per capita has steadily fallen since 1961 while it has risen everywhere else” (Bunting 2008).

More than elsewhere in the world, smallholder agricultural growth is critical for poverty alleviation in the subcontinent (Deininger and Byerlee 2012). Agricultural growth was found to be five times more effective in reducing poverty than non-farm growth in low-income countries but 11 times more so in Sub-Saharan Africa (Christiaensen, Demery, and Kuhl 2011; FAO 2012). The population of the region is expected to increase at 3 percent annually to more than 1 billion by 2025 (FARA 2003). Climate change is predicted to increase the variability of precipitation in Sub-Saharan Africa, increasing the risks associated with rainfed farming and posing new challenges of drought mitigation and adaptation. At the turn of the millennium, FARA (2003) estimated that Sub-Saharan Africa's agricultural economy must grow at a rate of 6 percent per year to provide for growing population, achieve food security, attack rural poverty, and speed up economic growth in a sustainable manner—and irrigation is the key to accelerating such growth. Given little irrigation development in Sub-Saharan Africa so far, there is enormous scope for expanding smallholder irrigation areas at modest investments over a short period.

Sub-Saharan Africa's Irrigation History

Sub-Saharan Africa had ancient traditions of rain-adapted farming in different parts—exemplified best by age-old décrue irrigation in northern Mali[1]—until the colonial powers introduced large canal irrigation systems, such as Office du Niger in Mali and Gezira in Sudan. Unlike in Asia, colonial irrigation systems in Sub-Saharan Africa were designed and managed as globally integrated agribusinesses, imposing monocrop regimes, providing all inputs, and marketing all outputs, with the African farmer having little entrepreneurial role (Shah 2009; Shah, Verma, and Pavelic 2013). With the end of colonialism, this model of irrigation management stagnated and declined as emphasis shifted to "social and not so much the productive character of irrigation" (Ertsen 2006). Large and small irrigation schemes continued to be built and managed by bureaucracies, mostly with foreign assistance and expertise. In the postcolonial era, efforts were made to turn over the management of preexisting and new systems to local communities but with variable outcomes (Shah et al. 2002). Decline in operation and maintenance, lack of institutional reform, bureaucratic inefficiency, poor service delivery, and lack of demand for irrigation all led to severe deterioration in the performance of public and community-managed irrigation systems in Sub-Saharan Africa, as elsewhere in the developing world (Alam 1991, 165; ICID 2010). With its low population density and dispersed farming areas, irrigation projects needed to either provide longer canals per irrigation acre or populate the command area by (often forcibly) relocating farmers near canals. The latter was easier under colonial powers who could treat irrigation landscapes as *tabula rasa*, which modern governments find hard to do. As a result, at about US$10,000 per hectare, centrally planned large-scale irrigation projects turned out costlier to construct in Sub-Saharan Africa than elsewhere in the developing world (ICID 2010; Lankford 2009). Thus, between 1980 and 2000, international financial institutions became increasingly reluctant to invest in large canal irrigation projects in Sub-Saharan Africa. Many preexisting colonial (or in South Africa, the apartheid era) irrigation systems constructed to benefit smallholders continued to be managed in a centralized manner as "estates." But the performance of these small systems—in terms of productivity, equity, and sustainability—was no better than large ones (Barnett 1984; Carter 1989; Perret 2002; Shah et al. 2002).

Green Shoots of Smallholder Irrigation

Since the 1980s, however, small pockets of informal smallholder irrigation have emerged throughout Sub-Saharan Africa, supported sometimes by NGOs and donors, using manual or motorized pumps to lift small amounts of water from ground or surface sources to irrigate garden and field crops (Allaire 2009; Eguavoen et al. 2012; Giordano and de Fraiture 2014; Lankford 2009). Toward the end of the 1980s, Brown and Nooter (1992) found these thriving in Burkina Faso, Cameroon, Chad, Mali, Mauritania, Niger, Nigeria, and Senegal. Smallholder farming in this discourse is taken to mean "family farming" as distinct from operating a commercial farm as described by Toulmin and Gueye (2005).

Behind this groundswell in small-scale, informal smallholder irrigation is mostly private initiative by individuals or small groups of smallholders. These schemes mobilize water from temporary shallow wells, ponds, streams, rivers, and other sources; they often involve lifting by manual or motor pump and conveyance of water through open channels or pipes or both (Adams and Carter 1987; Carter and Howsam 1994; Eguavoen et al. 2012; Lankford 2009). Common to these are several distinct features: a new entrepreneurial model of irrigation organization in which the smallholder was the decision maker rather than a laborer; the technology used was familiar and affordable; and institutional arrangements promoted farmer management, either in groups or individually. Critical to their vibrancy is not the size but the ownership-management model:

> *Small-scale irrigation is not large-scale formal irrigation made small. It is perhaps in the management element that the key difference lies. In a small system, there are no tiers of management as in large-scale schemes. The farmer alone decides when to irrigate and how much water to apply, when to start and stop pumps or other appliances, and generally runs the entire scheme with the help of the family or local community members. (Vaishnav 1994, 524)*

An early study noted that "…almost all successful irrigation occurs on plots owned and managed by individuals with individual water supply control" (Brown and Nooter 1992, 4). Researchers noted several advantages of smallholder irrigation systems that were entirely farmer-led and farmer-driven. Allaire (2009) noted that small-scale irrigation, especially based on shallow groundwater, arguably has the multiple advantages of ubiquity, immediacy, low cost, drought resistance, farmer management, spatial equity, on-demand water availability, and conveyance efficiency. However, implicit in the notion of "success" was financial and ecological sustainability, demand-driven irrigation service, and beneficial impact on smallholder household economy (Imfeld 2007).

FLSI Impacts in Sub-Saharan Africa

Researchers have documented different types of structures and institutional arrangements even within FLSI. A small group of farmers working together to divert water from a stream is FLSI. Thousands of women farmers using buckets or treadle pumps to water tomatoes or other vegetable crops are also considered FLSI. Global FLSI boom had these in early stages but, over the years, has come to be dominated by motor pumps, wells, and flexible pipes. Is the trend in Sub-Saharan Africa going to be any different?

In 2011, the Rockefeller Foundation tasked the International Water Management Institute (IWMI) to explore whether FLSI delivers similar productivity and livelihoods benefits in Sub-Saharan Africa as elsewhere in the world. IWMI and its partners interviewed a sample of 1,550 smallholders in nine Sub-Saharan Africa countries, shown in map 1.1[2]: 399 pure rainfed farmers; 366 farmers who used gravity flow irrigation, mostly from government canals; 413 farmers who used manual irrigation (bucket or treadle pump); and 362 who used motor pumps for irrigation from dug wells or open water bodies (as seen table 1.1). The survey showed that smallholders interviewed all preferred irrigated farming except for those who pursued rainfed farming by choice in Burkina Faso, Mali, and Niger, where they have larger land and livestock holding.

The survey showed hardly any difference among rainfed farmers, canal irrigators, and manual irrigators in the value of output per acre or per family worker. Rainfed farmers and canal irrigators mostly grew grains for family subsistence. Manual and motor pump irrigators grew market crops. However, motor pump irrigators spent twice as much as the other groups on inputs and generated more than three

MAP 1.1. Nine Countries in Survey of Smallholders in Sub-Saharan Africa

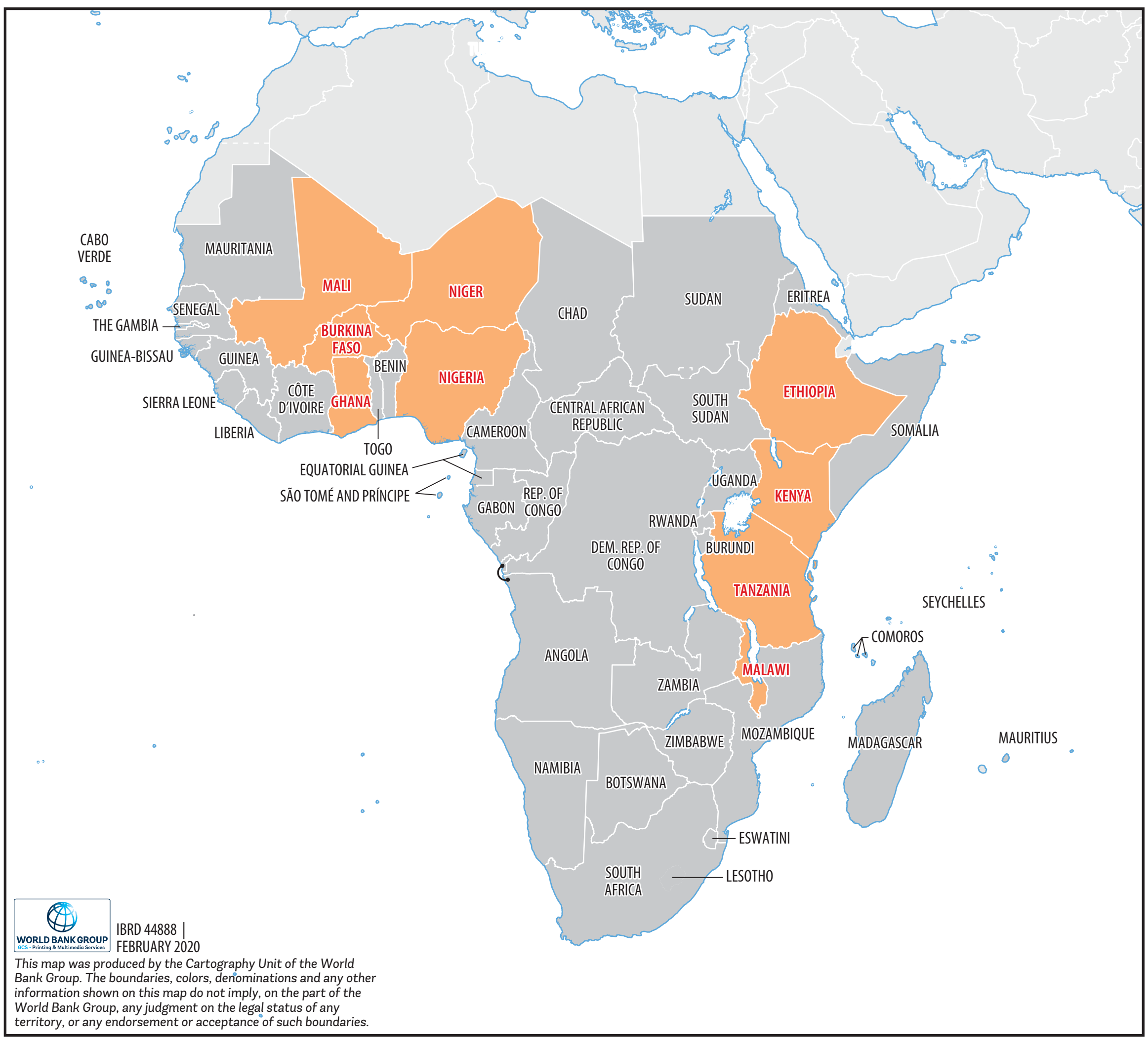


TABLE 1.1. Impact of Different Modes of Irrigated Agriculture on Smallholder Farming in Nine Sub-Saharan African Countries

	Rainfed (399)	Gravity flow (366)	Manual lift (413)	Motor pump (362)
Level of year-round on-farm water control	Low seasonal	Moderate seasonal	+High seasonal	High perennial
Farmer investment in irrigation	0	0	US$49 (15–155)	US$1016 (350–2,650)
Number of crops taken per year	1–2	1–2	3–5	3–9
Kind of crops	Subsistence grains	Subsistence grains	Vegetables for market	Vegetables for market
Input intensification (cash US$/acre	59	72	84	178
Value of output/acre (US$)	405	414	398	1,413
Value added/family worker (US$)	319	325	307	1,092
% who felt secure tenure	62	45	67	65

Source: Shah, Verma, and Pavelic 2013.

times the income per acre and per worker. Pump-irrigated farms face far less production risk; and even though our sample motor pump irrigators spent more on buying their pumps than their Asian brethren did, the investment was well worth it. Other researchers have come up with similar results. IWMI studies in Ethiopia and Ghana showed pump-irrigated tomato and onion deliver three times larger income compared with rainfed cereals and twice that of irrigated sorghum and teff (Hagos et al. 2009).

Four features of our sample stood out: First, motor pump irrigators were invariably wealthier and had a larger overall household asset base, suggesting a strong scale bias in motor pump use. Second, and relatedly, in the irrigation aspirations of rainfed farmers, a well of one's own, motor pump, and flexipipe was top preference; very few listed manual irrigation as a preferred option. Third, women farmers dominate manual irrigation and men farmers dominate motor pump irrigation. Fourth, capital constraint and high fuel costs were far more of a deterrent in motor pump irrigation than repair and maintenance problems (Shah, Verma, and Pavelic 2013).

Need for Speed

If global experience since the 1990's is any guide, farmers and governments will lay greater emphasis for hastening agricultural growth "on small-scale irrigation as a viable alternative to large-scale projects whose benefits were increasingly being questioned" (Woodhouse et al. 2017). If farmers increasingly wrest irrigation initiative, FLSI expansion in Sub-Saharan Africa will move from a rain-adapted farming system to a farming-adapted irrigation regime. In turn, there will likely be a greater role for individual or small group initiative in creating and managing irrigation; there will be greater use of water-lifting devices, movement from manual to mechanical pumps, a mix of subsistence and market crops rather than subsistence crops alone, and, in general, greater intensification and diversification of smallholder farming system driven by year-round, on-farm water control.

An estimated 85 percent of Sub-Saharan Africa's population lives more than 10 kilometers from a major river or lake, and they are unlikely to benefit from recession or gravity irrigation (World Bank 2018). This means that FLSI development will rely increasingly on scavenging water from small reservoirs or shallow groundwater. Chances are that irrigation schemes that require complex collective

TABLE 1.2. Irrigated Arable Land and Freshwater Withdrawals for Irrigation in Sub-Saharan Africa and South/Southeast Asia

	Total irrigated area in 2009 (Mha) (% of cultivated area)	Increase in irrigated area in 1970–2009 (Mha)	Area irrigated by groundwater (Mha)	Total freshwater withdrawals in 2009 (km^3) (% of total for agriculture)	Withdrawals of IRWR in 2009 (%)
Sub-Saharan Africa[a]	7.2 (38)	3.1	0.4	121 (87)	3
South/Southeast Asia[b]	97.6 (40)	48.5	48.9	1,173 (90)	33

Source: Data are from AQUASTAT (database), Food and Agriculture Organization of the United Nations, Rome, July 25, 2013, www.fao.org/nr/aquastat.

Note: IRWR = internal renewable water resources; km^3 = cubic kilometer; Mha = million hectare.

a. Irrigated area is called "area equipped for irrigation" in this database.

b. South Asia includes Bangladesh, India, Pakistan, Nepal, Sri Lanka. Southeast Asia includes Cambodia, Indonesia, Laos, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand, and Vietnam.

action will gradually give way to smaller, simpler irrigation structures driven by individual or small group entrepreneurship. This too will favor greater reliance on groundwater because, as Donald Worster (1992, 313) has noted, "Subsurface deposits often require little social organization."

Nowhere in the emerging world has the Green Revolution formed root in rainfed farming areas. Colonial engineers introduced tubewells in Botswana in the 1930s (Closas and Molle 2016), about the same time they introduced them in northern India. However, the tubewell technology overran South Asia and jumpstarted its Green Revolution but failed to spread in Sub-Saharan Africa. The ambition of the Forum for Agricultural Research in Africa to accelerate agricultural growth rate in Sub-Saharan Africa to 6 percent per year is unlikely to be met without a major thrust on accelerating FLSI development.

Sub-Saharan Africa's own experience highlights the criticality of irrigation: 7 million irrigated hectares out of 175 million cultivated hectares account for 38 percent of total agricultural output (You et al. 2011). Sub-Saharan Africa withdraws barely 3 percent of its water resources for irrigation, as compared with 33 percent for South and Southeast Asia (table 1.2). In nearly 40 years, from 1970 to 2009, Sub-Saharan Africa added just 3.1 million hectares of irrigation, whereas South and Southeast Asia added 48.5 million hectares, almost wholly by growing groundwater irrigation. Even so, over the past 30 years, irrigation has been off the policy radar in Sub-Saharan Africa.[3]

Despite huge scope and need, the pace of growth of such smallholder irrigation in Sub-Saharan Africa has remained tepid at about 3 percent per year and just 5 percent of agricultural land (6 million hectares) is equipped for irrigation (FAO 2011a; Makin 2016). Sub-Saharan Africa is adding about 60,000 hectares per year to its stock of smallholder irrigation, and this too remains concentrated in a few countries. In comparison, South Asia added, on average, 1.5 million hectares per year of smallholder irrigation between 1985 and 2010 in a much smaller geography than Sub-Saharan Africa. In a G8 summit in July 2009, U.S. President Obama said:

> *There is no reason why Africa cannot be self-sufficient when it comes to food. It has sufficient arable land. What's lacking is the right seeds, the right irrigation, but also the kinds of institutional mechanisms that ensure that a farmer is going to be able to grow crops, get them to market, get a fair price. (Lankford 2009)*

Global experience suggests that distributed FLSI is "the right irrigation" for Sub-Saharan Africa at this juncture. If countries in this region are to seriously pursue aggressive growth in smallholder-irrigated agriculture, they must not ignore factors that drove a veritable boom in smallholder irrigation all over the world, especially in the North China Plain and South Asia. In this paper, we attempt to recapture the history of the global smallholder irrigation boom to understand its triggers and drivers and to consider what might accelerate Sub-Saharan Africa's tepid growth of smallholder irrigation.

Notes

1. A highly sophisticated system of recession agriculture practiced 10,000 years ago. According to Imfeld (2007), "décrue is not just an irrigation system but also closely related to a method of interplanting and transplanting different crops—truly an art that allowed farmers to expand the size of their fields."

2. Ethiopia, Kenya, Malawi, and Tanzania from the east and Burkina Faso, Ghana, Mali, Niger, and Nigeria from the west.

3. "Although large expansion of irrigated agriculture was a pivotal component of past green revolutions, it is not given much attention in Sub-Saharan Africa. At issue is whether this lack of attention is an oversight" (Cassman and Grassini 2013).

Chapter 2
Global Boom in FLSI

In the global history of smallholder irrigation, the period beginning 1950's represents a new era in the poor and emerging economies of Asia. The dominant mode of irrigation we find in the 21st century is quite different from both the traditional communal irrigation (Hunt 1986; Sakthivadivel, Gomathinayagam, and Shah 2014 on tank irrigation; Shah 2009, 2018) and the government-managed large-scale canal irrigation of colonial and postcolonial times. Much irrigation in Bangladesh, India, Jordan, Mexico, Morocco, North China, the Islamic Republic of Iran, and Pakistan is akin to Sub-Saharan Africa's smallholder irrigation described in chapter 1. It has been labeled private, informal, small-scale, atomistic, and so on. Because this new era is characterized by irrigation expansion driven by small-farmer initiative and enterprise, it is also being labeled *farmer-led smallholder irrigation* (FLSI) development, which is the term we use in this paper.

Farmer initiative and communal enterprise were also characteristics of traditional community irrigation structures of earlier times (tanks in Southern India and Sri Lanka; *quanats* in Afghanistan, the Islamic Republic of Iran, Pakistan, and elsewhere in West Asia; hill irrigation systems like *kuhls* in the Himalayas). However, FLSI in the new era does not always require large-scale, continual collective community mobilization in construction, maintenance, and management of irrigation structures. FLSI also differs from large basin-scale public irrigation projects, which, for more than 150 years, dominated the irrigation scene in Egypt, colonial India, Indonesia, Mali, Morocco, Sri Lanka, Sudan, Thailand, and Vietnam. FLSI does not require government initiative in irrigation assets, although it has benefited from and been supported and regulated by government policies. Finally, most community and government irrigation systems sourced water from surface reservoirs, transported it in open channels, and used kinetic energy to transport water. Most FLSI throughout the world depends on groundwater, uses mechanical energy to drive it, and uses pipes or channels to transport water to crop root zone.

Irrigation Adapted to Farming Rather than Farming Adapted to Irrigation

We can thus define FLSI to include small-scale irrigation systems (0.1 to 50 hectares) created and managed by smallholders or their communities or informal/formal groups using surface water, groundwater, or peri-urban wastewater on a financially and managerially self-sustainable basis with or without external support from governments, nongovernmental organizations (NGOs), or other agencies. They may use energy in lifting and/or delivering water to crops and exclude large or medium-scale government-managed irrigation systems, except when farmers or their groups have assumed full responsibility of their operation and maintenance on a sustainable basis. Throughout history, community- and state-managed irrigation systems obliged smallholders to adapt farming to the discipline imposed by irrigation managers, but FLSI allows farmers to adapt irrigation to their needs. With the land frontier closing, the key motive that drives FLSI is smallholder's need for year-round, on-farm water control to intensify and diversify their farming systems to improve livelihoods.

Growing Role of Motor Pump

FLSI is firmly grounded in the agrarian context of a landscape and has, therefore, followed different evolutionary trajectories in various countries. Woodhouse et al. (2017) studied FLSI in Sub-Saharan Africa and defined *farmer-led irrigation development* as a

> process where farmers assume a driving role in improving their water use for agriculture by bringing about changes in knowledge production, technology use, investment patterns and market linkages, and the governance of land and water. In the process, farmers rely on and influence neighbouring farmers, agro-dealers and traders, craftspeople, agriculture extension agents and irrigation engineers, administrative authorities, local and national policy-makers, civil society and development aid agents. (Woodhouse 2017, 216)

They describe four examples of FLSI among Sub-Saharan African smallholders: (a) furrow irrigation in mountain areas; (b) petrol/diesel pump irrigation from shallow groundwater or reservoirs; (c) peri-urban wastewater irrigation; and (d) groundwater irrigation in valley bottoms (Woodhouse et al. 2017). Elsewhere in the world, FLSI has relentlessly moved toward motor pump-based private/small group irrigation scavenging water from whatever source is available. There seems to be no reason why this trend will not gather momentum in Sub-Saharan Africa too. Table 2.1 outlines some key features of FLSI and contrasts it with community-led traditional irrigation and state-led public irrigation systems.

Global Boom in Pump-Driven FLSI

There are no firm estimates of global expansion in FLSI. But there are many indications that pump irrigation from groundwater and surface water bodies—reservoirs, canals, rivers, and drains—has

TABLE 2.1. Comparing Community-Led, State-Led, and Farmer-Led Smallholder Irrigation

	Community-led irrigation	Government-led irrigation	Farmer-led smallholder irrigation
Examples	Irrigation tanks of south India and Sri Lanka; qanats of West Asia; *surangams* of north Kerala; kuhls of the Himalayas; Indonesian *subaks*	Lower Indus irrigation system (16 Mha); Sardar Sarovar irrigation project (1.8 Mha); public tubewells of Uttar Pradesh	Shallow/deep tubewells; river lift irrigation systems; treadle pumps; tubewell irrigation service markets; tubewell companies
Size	One or a few villages; 10–250 ha	50–2 million ha	0.1–10 ha
Ownership and management	Irrigation community	Government management	Individual farmer, a small group, or a farmers' company/cooperative
Dominant institution	Collective action; "cooperation by mutual coercion"	Top-down bureaucracy	Decentralized, informal irrigation service markets
Current state	Stagnant or declining	Stagnant; increasingly subservient to FLSI	Booming in South and West Asia and North China; growing rapidly in Sri Lanka, Thailand, and Vietnam
Key governance challenge	Institutional sustainability; competition with FLSI	Financial and institutional sustainability; competition with FLSI	Chaotic, unregulated growth; threat of resource depletion; managing negative externalities

Source: Author's formulation.
Note: FLSI = farmer-led smallholder irrigation; ha = hectare; Mha = million hectare.

TABLE 2.2. Area Equipped for Irrigation and Percentage of Cultivated Land

Continent regions	Subregions	Total area equipped for irrigation (Mha)			By groundwater: Area	By groundwater: % of total	Total irrigation as % of cultivated land		
Year		1973	1993	2013	2013	2013	1973	1993	2013
World		196.1	265.9	325.1	124.7	38.4	13.6	17.3	20.6
Sub-Saharan Africa		4.2	6.1	8.2	0.4	5.4	2.6	3.3	3.4
Asia		132.8	178.6	232.7	90.0	38.7	25.8	31.6	40.9
	South Asia	49.6	72.1	98.0	55.5	56.6	23.5	33.6	45.7
	South East and East Asia	51.7	56.0	73.9	21.3	28.9	46.0	39.5	56.0

Source: Data are adapted from AQUASTAT (database), Food and Agriculture Organization of the United Nations, Rome www.fao.org/nr/aquastat.
Note: Mha = million hectare.

contributed the bulk of the increase in irrigation during the past 50 years. Data from the Food and Agriculture Organization of the United Nations, summarized in table 2.2, suggest global irrigated area to have increased from 196 million hectares to 328 million hectares between 1973 and 2013 when total area wetted by groundwater was placed at 127 million hectares. If we assume that groundwater irrigation was insignificant in 1973, then we can infer that the bulk of the global growth in irrigated area since the early 1970's of some 132 million hectares has been contributed by groundwater.

During these 40 years, Sub-Saharan Africa has remained a minor player, growing its irrigated area from 4.2 million hectares to 8.2 million hectares, with groundwater contributing all of 0.4 million hectares in 2013. During the same period, South Asia doubled its irrigated area from all sources from 49.6 million hectares to 98.0 million hectares with groundwater accounting for 55.5 million hectares in 2013. The rest of Asia also grew area equipped for irrigation from 83.2 million hectares to 134.7 million hectares with groundwater contributing 34.5 million hectares in 2013.[1]

The rapid rise in the numbers of mechanized irrigation pumps—diesel, petrol, kerosene, and electricity—is by far the best indicator of the "silent revolution" in FLSI in much of Asia. In India, there were about 5,000 mechanized tubewells in 1951 (Dhawan 1982, 2), but their numbers soared to 19 million at the turn of the millennium and may have further increased to about 25 million since then (Molle, Shah, and Barker 2003). In Bangladesh, the total number of shallow tubewells increased from 45,000 in the early 1985 to more than 800,000 by 1999 (BADC 2013) and in the 2000s exceeds 1.2 million. In 1980, tubewell irrigation accounted for just 15 percent of irrigated area in Bangladesh, but by 2000, this had increased to 71 percent; low-lift pumps on surface water bodies accounted for another 15 percent (BADC 2013).

In Pakistan, tubewell numbers increased from fewer than 200,000 in 1980 to 1.1 million in 2015 (PBS 2012). In 2000, Thailand had 3 million small pumps used for surface and groundwater irrigation, and the Islamic Republic of Iran had 365,000 heavy-duty pumps producing 45 cubic kilometers of groundwater for irrigation. Vietnam and Sri Lanka were the latest to kick-start their pump-driven FLSI. In 1980, Vietnam had about 30,000 pumps, which soared to 150,000 in 1991 and then to 800,000 in the next eight years (Barker and Molle 2004). In Sri Lanka, the proverbial hydraulic society with a rich tradition of tank irrigation, agro-wells with mechanized pumps increased from a few thousand in 1991 to more than 100,000 by 2000 (Molle, Shah, and Barker 2003). China had hardly any small private pumps until 1970, but there was an explosive growth in small tubewells and pumps to more than 17.5 million in 2000 (FAO 2011b).

Distinguishing Features of FLSI

This pump revolution in Asia had all the characteristics that Woodhouse et al. (2017) ascribed to the FLSI they studied in Sub-Saharan Africa: (a) farmers invest substantially; (b) farmers interact among themselves and with external agencies (landholders; tenant farmers; intermediaries such as pump-owners, traders, masons, and mechanics; and agents from governmental, nongovernmental, and international organizations) and markets in support of their irrigation development; (c) rather than being driven by officially identified "irrigation potential," FLSI is driven more by ease of development, maintenance, and operation, individually or within a small group; (d) formal land tenure is not a prerequisite as seasonal tenants easily buy irrigation service from tubewell owners; and (e) many benefit, but some lose.

In completing the transition from farming adapted to irrigation to irrigation adapted farming,[2] FLSI in Asia had several markers:

- Marked preference for lifting water rather than gravity flow
- Scavenged water from any reliable perennial source—surface water, groundwater, wastewater, or irrigation drains
- Individual or small group ownership and management
- Gave rise to informal local markets in irrigation service that benefited pump owners and pumpless resource-poor farmers (Meinzen-Dick and Sullins (1994) for Pakistan; Palmer-Jones (1989) for Bangladesh; Shah 1993 for India; Wang et al. (2014) for China)
- Access to FLSI reduced farmers' patronage of public irrigation systems and participation in traditional community irrigation systems; share of public and community irrigation stagnated or declined in relative and even absolute terms

Notes

1. Data are from AQUASTAT (database), Food and Agriculture Organization of the United Nations, Rome, accessed on October 13, 2018 http://www.fao.org/nr/water/aquastat/tables/WorldData-Irrigation_eng.pdf.

2. Best captured in this quote by Kikuchi et al. (2003): "In the history of irrigation and irrigated agriculture in the monsoonal tropics of Asia, the last few decades of the twentieth-century would be remembered as the period of well and pump diffusion. It was a trend that enabled individual peasant farmers to irrigate their crops at their discretion, as opposed to the practice in gravity irrigation systems where decision making as to water allocation and distribution rests on groups of farmers or on government agencies."

Chapter 3
Triggers and Drivers of FLSI in Asia and Elsewhere

What triggered the pump-driven farmer-led smallholder irrigation (FLSI) adoption in Asia and elsewhere? More importantly, what were the drivers that transformed FLSI into a global boom?

Triggers

The specific triggers vary. In India, where the FLSI boom began first, the government of United Provinces (today's Uttar Pradesh) began promoting electric tubewells as early as the 1920s as small hydroelectric plants began to generate hydropower on the Ganga Canal. The Bengal famine of 1943, which led to 3 million starvation deaths, highlighted India's precarious food security and its inability to cope with droughts. Soon after World War II, India launched some of the largest tubewell construction programs, which excited the Anglo-American tubewell industry and drew in their geological exploration capabilities for government contracts. During the 1950s, the United States Geological Survey was roped in to undertake a broad groundwater reconnaissance survey under Project Elephant, which imported American rigs, tubewell machinery, and even trucks to move the rigs around. The project actually generated little scientific data of value, but scores of local technicians were trained as drillers, and many launched their own start-ups, drilling borewells for farmers. One of these, Gurnam Singh, a farmer's son, purchased a used rig to drill borewells and, in time, became a Mercedes-driving tubewell tycoon. Exploring groundwater became an agricultural enterprise more than geological (Subramanian 2017).

Although farmers remained lukewarm toward tubewell irrigation, governments kept pushing it through various means. India was once again visited by a serious drought in 1965-66; starvation deaths were avoided but only by food aid shipments from the United States negotiated at humiliating terms by Indira Gandhi. This redoubled the government's commitment to food self-sufficiency. Planeloads of improved seeds of Mexican dwarf wheat variety were flown in, and an intensive agricultural development program was launched in a fertile tract of northwest India to give a push to food production. When High-Yielding variety (HYV) seeds and fertilization met results only with tubewell irrigation, a further impetus was imparted to the latter's promotion. The government of India's Exploratory Tubewell Organization was made part of the agriculture ministry in the belief that "agriculture is the greatest beneficiary of groundwater" (Subramanian 2017). For decades, groundwater irrigation in India boomed under this ministry while irrigation bureaucracy busied itself with dams and canals. The agriculture ministry negotiated several World Bank loans to establish public tubewell programs, some with innovative designs of piped distribution systems (Chambers, Saxena, and Shah 1989) which in time triggered the private tubewell boom.

Pakistan was somewhat better placed in regard to food security because it inherited a vast canal irrigation system in the Indus basin. But after decades of operation, command areas in Punjab and Sind were fighting serious challenges of water-logging and salinization. Although the World Bank-supported Salinity Control and Reclamation Project (SCARP) tubewell program to pump saline groundwater into canals to lower groundwater and augment tail-end canal supplies eventually failed, it exposed farmers to the promise and potential of tubewell irrigation.

In China, tubewell installation began in the late 1950s, but numbers began accelerating during the 1970s. "According to official statistics, during 1965 to 2003, the number of tubewells increased from 0.2 million to 4.7 million" (Zhang et al. 2008, 706) and to 16 million in 2010 (Huang et al. 2012). The main trigger of pump-driven FLSI adoption was the breakdown of collective farming and the institution of the household responsibility system. Village committees continued to operate the commune-era collective tubewells, but private tubewells and water markets soon emerged and began to crowd them out, offering better service. As Wang et al. (2007, 37) asserted, "Arguably, there have been more tube wells installed in China over the last quarter century than anywhere else in the world."

Bangladesh followed a different model that discouraged private tubewell expansion. Some nongovernmental organizations (NGOs), like Bangladesh Rural Advancement Committee (BRAC) and PROSHIKA used donor funds to establish heavy-duty tubewells to sell irrigation service to farmers. Others, like International Development Enterprises (IDE) aggressively promoted a range of affordable treadle pumps, which exposed farmers to the benefits of groundwater irrigation of vegetables and boro (summer) rice (Shah et al. 2000). However, as soon as affordable motor pumps became available with liberalization of imports of irrigation equipment during the 1980s, Bangladeshi farmers disadopted treadle pumps *en masse*; thus, began a motor pump-driven FLSI boom that turned Bangladesh from a perennial rice importer to a rice exporter in a single decade.

Supply-Side Drivers of the FLSI Boom

In his seminal book *Diffusion of Innovations,* Everett Rogers (1962) identified five stages through which a new technology passes before its widespread adoption:

- Awareness: First point of exposure to the new technology
- Persuasion: Potential adopter collects information on pros and cons of the technology
- Decision: Potential adopter decides whether to adopt the technology
- Implementation: Potential adopter actually adopts the technology and explores its pros and cons
- Confirmation: After using the technology, adopter evaluates options to continue use or disadopt

The triggers discussed in this chapter merely helped create awareness among farmers about pump-driven FLSI and created a felt need for it (persuasion). However, it took a constellation of demand- and supply-side factors to mainstream FLSI adoption (decision and implementation) to create fertile grounds for what turned out to be a pump-driven FLSI revolution. It is hard to pinpoint any one factor as a trigger because they interacted with and reinforced one another. Key supply-side drivers were:

- *Resource development before management:* When South Asia and China began growing their pump-driven FLSI, national, and global public policy environment was highly supportive of poverty alleviation and equitable economic development with hardly any emphasis on environment and sustainable resource management (Chambers, Saxena, and Shah 1989). As a result, state machinery, political leaders, and international donors put their full weight behind programs to support FLSI development without extensive mapping, exploration, and assessment of available resources. Decades later, this development-first-management-after approach created severe groundwater externalities, with which China and India are now struggling to cope.

- *Affordable pumps and boreholes:* Irrigating gardens from dug wells using human/animal power has been an age-old tradition in Asia, though slow and costly. Arrival of mechanical pumps and tubewells drastically reduced the time and cost involved in lift irrigation. In large-scale survey of farmers in China, Wang et al. (2007) found that over the years, average pump size grew but average cost of the pumps fell as a result of economies of scale—to levels smallholders could actually afford. As argued later, Chinese overcapacity in manufacturing affordable motor pumps energized the FLSI boom not only in China but also throughout Asia (Huang, Rozelle, and Hu 2007).
- *Aggressive government promotion:* In many parts of India, modern tubewell irrigation was introduced during the 1920s, but farmers expressed strong resistance. To popularize tubewell irrigation, many Indian states, notably Bihar, Gujarat, Tamil Nadu, and Uttar Pradesh established thousands of heavy-duty government-managed public tubewells to provide affordable irrigation to smallholders. During the 1950s, the World Bank actively funded India's public tubewell programs and Pakistan's SCARP tubewell program with the idea of using tubewells as lateral drains to ease secondary salinity (Bhatti 1987). In Bangladesh, NGOs took initiative in spreading awareness about the benefits of tubewell irrigation by supporting NGO-managed group tubewells (Palmer-Jones 1989), just as the United States Agency for International Development did on a small scale in terai areas of Nepal. The government of Sri Lanka supported an agro-well irrigation program to popularize FLSI. In North China, in the first decade of the household responsibility system, group tubewells managed by village committees were encouraged and supported with state financial aid although the private tubewell boom took off without much government promotion and support.
- *Rural electrification drive:* During the 1950s, electricity use emerged as a key marker of progress. Countries like India began to invest heavily in rural electrification as a strategy of accelerating irrigated agriculture based on tubewells.[1] Special incentives were offered to farmers to use electricity for tubewell irrigation. Connection costs were waived; farm tariffs were subsidized; and local administration was pressurized to promote tubewell adoption among farmers. As numbers of electric tubewells increased, transaction costs of metering dispersed tubewells and billing their electricity use also increased. One by one, India's electricity utilities gave up metering and began charging tubewells a flat monthly tariff based on their rated capacity. Some politicians abolished farm tariffs altogether. Power subsidies emerged as the biggest driver of FLSI boom in western India. The policy soon got entrenched in a perverse political economy of its own, from which India has yet to extricate itself. Bangladesh, Nepal, Pakistan, Sri Lanka, and even China were less aggressive in promoting groundwater-based FLSI and did not take any of these measures. Because none of these countries had an efficient pump industry, their FLSI development lagged India's by a decade or more.
- *Institutional credit support:* As prime minister of India, Indira Gandhi made *garibi hatao* (remove poverty) her government's credo. In one of her policy moves, she nationalized major private banks and then obliged them to liberally lend to farmers at subsidized interest rates (even without collateral, in the case of marginal farmers) to stimulate agricultural modernization. This policy of priority sector advances created a liberal institutional credit environment that fed growing demand for FLSI after the 1970s.

- *Free boring scheme, million well scheme:* The Green Revolution technology, introduced in northwestern India during the 1960s, made tubewell irrigation highly profitable. Adopters of HYV seeds and chemical fertilizers realized that returns to these inputs were low in the absence of timely irrigation. Studies began to find massive yield-gap among adopters with and without tubewell irrigation. FLSI based on shallow tubewells (STWs) and small diesel pumps became a favorite of politicians looking for schemes to propitiate farmers and win their votes. The government of Uttar Pradesh implemented a free boring scheme in which the government absorbed the cost of making a borewell, with banks offering low-interest loans for diesel pumps. The scheme became an instant hit; in Ganga basin's richly recharged alluvial aquifers, STWs emerged as miracle irrigation technology. Devi Lal, a farmer-turned deputy prime minister of India, followed suit and announced a million well scheme to extend the benefits to other states. Private diesel-pump dealers emerged as implementation stars in these schemes. Studies showed that bureaucrats, bank officials, and pump dealers agreed on uniform rates of speed money (that is, bribes) to operate a smooth, seamless high-volume-low-margin regime of implementing the million well scheme. In the process, pump dealers laid red carpet for small farmers, cutting red tape and turnaround time to commission their STWs (Shah 2001).
- *Maintenance and repair:* As tubewell density increased in North China and South Asia, an entire new cottage industry emerged to keep the tubewell economy running. Almost every village in India has at least one but as many as a dozen diesel-pump mechanics or motor rewinders and related service providers. Likewise, there is a drilling rig operator for every five to 10 villages available on demand. Competition among them has pared the price of their services down to levels farmers can afford. This is the underbelly of Asia's FLSI economy—totally in the informal sector outside the gaze of the government and the tax collector—that keeps it going.
- *Liberalization of imports of irrigation equipment:* In Bangladesh, a World Bank team triggered an FLSI boom simply by getting a policy reform implemented. Until the mid-1980s, it was difficult and expensive for a Bangladeshi farmer to access a diesel pump because the import was monopolized by public sector Bangladesh Agricultural Development Corporation (BADC) (Palmer-Jones 1999). NGOs aggressively promoted treadle pumps, whose numbers crossed a million by 1995. BADC strongly discouraged unregulated private boom in STWs and instead constructed deep tubewells (DTW) following strict spacing norms and rented them out to groups and cooperatives to operate. In the early 1980s, the government of Bangladesh heeded the advice of a World Bank team to liberalize the import of irrigation equipment, in effect rejecting BADC's approach of government-regulated DTW development. In the next few years, Bangladesh was flooded with diesel/kerosene/petrol pumps of a great variety and prices, including used Chinese pumps for the price of IDE's treadle pumps. Farmers were quick to chuck treadle pumps and, after 1985, numbers of mechanized STWs in Bangladesh ramped up at a rate of 30,000 per year.[2] The area under boro rice—the fully irrigated presummer rice with assured high yield—grew *pari passu* with expansion of STW irrigation. Throughout the 20th century, east Pakistan and then Bangladesh had run a perennial rice deficit; in the decade after 1985, Bangladesh began exporting rice. Without spending a taka of public funds, Bangladesh managed an agricultural revolution by permitting FLSI to take off.
- *Specialized clusters of pump manufacturers and drillers:* The emergence of an efficient organization of pump manufacture and rig operators also aided in the affordability of FLSI in Asia. Growing demand

for groundwater-based FLSI resulted in geographic clusters of specialist providers of services and inputs. For example, Tiruchengode, a small town from Tamil Nadu, emerged as the drilling rig capital of India. This single town has anywhere between 7,000 and 20,000 truck-mounted rigs, each with a team of three operators. A similar cluster emerged in Telangana. They are always on a move, all over India, drilling boreholes in any geological formation at a modest cost, and they played a key role in accelerating groundwater-based FLSI in India (Sainath 2013). Similarly, Daxi town in Zhejiang province of eastern China emerged as the small-pump capital of not only China but also much of Asia (Huang, Rozelle, and Hu 2007).[3] Like Tiruchengode, Daxi has tens of thousands of microenterprises and pump assemblers. Most are unregistered, and each specializes in manufacturing one or a few parts of a small pump. Based on orders received, assemblers shop around for parts in the town and quickly dispatch the order. Chinese pumps are smaller than 8 kilowatts, weigh 8 to 15 kilograms, combine engine and pump in the same case, and are small enough for a farmer to carry on his or her shoulders. They are mostly unbranded, have a short life, but are easy to repair; in Daxi, they sell for as little as US$10 to US$20 (Huang, Rozelle, and Hu 2007). Most importantly, they are highly fuel efficient. Indian pumps have a long economic life and need little maintenance; however, they are 70 to 80 kilograms in weight and nearly twice as pricey as Chinese pumps, and they need more fuel per hour than Chinese pumps. Even Indian farmers today opt for Indian pumps only if they claim government subsidy; otherwise, they buy Chinese pumps over the counter. Japanese pumps are light, have a long life, and need little maintenance, but they are the priciest of all and very costly to repair. Over the years, as Bangladesh, Pakistan, Sri Lanka, and Vietnam liberalized their trade policies, Chinese pumps made deep inroads in these countries, crowding out Indian and Japanese pumps. Between 1993 and 2007, the value of China's pump exports increased by more than six times in Sri Lanka and more than 10 times in Bangladesh, the Philippines, and Vietnam (Huang, Rozelle, and Hu 2007). Chinese pumps have arguably played a large role in accelerating FLSI in much of Asia.

Demand-Side Drivers of the FLSI Boom

- *Dwindling farm size:* South Asia experienced a population explosion during the 20th century, which placed inexorable pressure on smallholder farming systems. Average farm size dropped from 3 hectares in 1900 to less than 1 hectare 100 years later (Shah 2009). Nowhere in the world, except in China and South Asia from 1980 to 2000, have so many people had to eke out a living from so little farmland. Smallholder groundwater revolution here is the "adjustment variable" that expanded the region's carrying capacity to feed its growing population (Boserup 1965). Subdivision and fragmentation of farms created strong pressure to intensify and diversify farming systems for subsistence and market produce, making dry-season cropping essential. This spurred the demand for pump-driven FLSI (Shah 2009).
- *Poor performance of public irrigation systems:* Public irrigation systems in much of Asia were not designed for flexible water deliveries all through the year. Moreover, thanks to deferred maintenance, poor management, and bureaucratic lethargy, they were unfit to meet growing demand for on-demand irrigation. Over time, their irrigation role declined to one of recharging the aquifers that supported groundwater-based FLSI (Molle, Shah, and Barker 2003; Shah 2009).

- *Stagnation in community irrigation systems:* Much the same fate met half a million irrigation tanks of South India; qanats of Pakistan, the Islamic Republic of Iran, and elsewhere; and other traditional community-managed irrigation systems. Their institutional requirements and managerial complexity made privately managed groundwater irrigation appear more attractive, and as more farmers turned to the new option, the older systems stagnated and declined (Molle, Shah, and Barker 2003). Declining performance of government and community irrigation systems was first the cause and then the result of the FLSI boom.
- *Irrigation service markets:* A powerful demand-side driver of the FLSI boom in the North China Plain and South Asia was the spontaneous emergence of informal, decentralized, village-level irrigation service markets. Investing in tubewell irrigation would be unviable for a small farmer simply because his small farm would use only a small fraction of its irrigation capacity. Selling irrigation service to neighboring farmers for a fee enabled tubewell owners to recover their costs while making reliable irrigation accessible to other marginal farmers (Shah 1993).
- *High-value market crops:* The main draw of pump-driven FLSI was the ability to take a dry-season harvest. Onslaught of STW irrigation in Bangladesh rapidly increased the planting of boro rice, which ensured household and national food security (Palmer-Jones 1999). Access to well irrigation enabled millions of dairy farmers in India to keep high-yielding animals that needed irrigated fodder in the dry season (Goswami et al. 2017). In Jordan, Morocco, and Spain, tubewell irrigation supported high-value export crops—fruit, vegetables, grapes, olives—for a lucrative European Union market.
- *Climate change:* Hydroclimatic change, which has led to long dry spells and fewer rainy days, has increased smallholders' dependence on irrigation. In South Asia, this is emerging as a new driver for irrigation from groundwater storage, which is often more reliable during dry spells and has greater value as a strategic buffer. According to the India Meteorological Department, before 1975, India witnessed 35 drought years in 216 years—on average, once every five years. Between 1976 and 2017, however, it suffered 14 drought years in 41 years—on average, once in three years (CSE 2017, 51). Between 2006 and 2016, a third of India's districts suffered four or more drought years, and since 1997, areas defined officially as drought prone have grown by 57 percent. India has also been experiencing increased frequency of multiyear droughts. According to the government of India, the country suffered only three multiyear droughts between 1901 and 1950 but 12 between 1951 and 2010. This increasing frequency of dry spells has increased farmers' dependence on groundwater-based FLSI.

Notes

1. The rural electrification program in India was launched with two distinct dimensions: (a) village electrification and (b) irrigation pump set energization (Samanta 2015).
2. The number of shallow tubewells increased from 30,000 in 1980 to 230,000 in 1988 (Palmer-Jones 1999, figure 4.3).
3. Before 1970, China's state sector manufactured large pumps used by communes and irrigation systems. But with the breakdown of communes, there was a sudden spurt in demand for small pumps that state-run factories could not meet, so many private factories arose to meet this growing demand within China and abroad. Between 1983 and 1989, Chinese exports of pumps soared from US$2.5 million to US$25 million and kept growing thereafter.

Chapter 4
Positive and Negative Impacts of the FLSI Revolution

The farmer-led smallholder irrigation (FLSI) boom around the world, but particularly in North China and South Asia, transformed smallholder agriculture in myriad ways. In the era of state-led canal irrigation, the landscape was divided between irrigation haves and have-nots because only areas commanded by a dam could receive irrigation (Shah 2009). The spread of pumps and boreholes made irrigation democratic, reducing the spatial inequity between irrigated lowlands and rainfed upland areas. As market for pumps and bores increased, scale economies kicked in so that pump irrigation could be developed quickly at an affordable cost almost everywhere.

Green Revolution

When the Green Revolution technology arrived in the form of high-yielding seeds and chemical fertilizers, it failed to produce notable results until tubewell revolution took off. Robert Repetto (1986) admitted that India's wheat revolution was in fact a tubewell revolution (Shah 2009). Long after the technology arrived, rice yields in Bangladesh, Pakistan, and much of South and Southeast Asia showed tepid growth of 1.5 percent per year. It was only after the shallow tubewell boom erupted in Bangladesh that its rice yields, led by presummer tubewell-irrigated boro rice crop, began growing at 2.6 percent per year between 1985 and 2000, turning a perennial rice importer into an exporter (Huang, Rozelle, and Hu 2007).

As Cassman and Grassini (2013, 204) noted:

> Contributions from expansion of irrigated area were at least as large as those from improved genetics and plant nutrition for two reasons. First, irrigation supports increased yields in regions where rainfall cannot fully meet crop water requirements by eliminating water deficits and by amplifying the benefits of fertilizer. Second, in combination with use of earlier maturing modern varieties, irrigation allows production of two or even three crops per year on the same piece of land in monsoonal tropical and subtropical climates that previously supported only one crop per year on rainfall.

Intensification and Dry-Season Market Crops

Pump irrigation's big attraction for Asia's smallholders was the freedom it gave to take a dry-season high-value crop for the market. Intensification and diversification of farming systems, made possible by year-round on-demand irrigation, helped smallholder irrigators improve their incomes and wealth. A survey of more than 17,000 farmers in India showed that farm households with wells or surface water access (compared with farm households without such access), contained 35 percent higher land-use intensity, 35 percent more livestock (cattle and buffaloes), 61 percent more income derived from milk and eggs, and 86 percent more in sales of poultry and livestock (World Bank 2018). Ramon Llamas, a leading hydrogeologist, highlighted groundwater's role in smallholder poverty alleviation as a result of its high economic productivity. In Spain, the expansion of groundwater use from

2 billion cubic meters in 1960 to 6.5 billion cubic meters in 2000 supported high-value agriculture that yielded water productivity as high as 12 euros per cubic meters, 50 times higher than surface irrigation (Custodio et al. 2009).

Made Famines History

One of the biggest effects of the global FLSI boom is that it has made famines history. Famines were endemic to South Asia. During Moghul and British India, droughts readily turned into famines, causing millions of starvation deaths. Famines hit all parts of South Asia—humid, semiarid, and arid—although some areas, such as Bengal, Bihar, Deccan, Gujarat, and Orissa, suffered more frequently than others. During the 18th to 20th centuries, famines took an estimated 60 million lives in South Asia. A meteorological drought readily turned into an agricultural drought and then to a famine.

However, since the much-studied Bengal famine of 1943, South Asia has faced many droughts but hardly any famine. Nobel Laureate Amartya Sen attributed lack of famines in India to its democracy. According to him, free press and democratic processes ensure that elected governments are forced to prevent famine. A competing hypothesis is that the boom in pump-driven FLSI made famines history in South Asia. Pakistan has been run by the army most of the time yet has faced no famine during the past 70 years. Many countries in Sub-Saharan Africa, under democratic and despotic regimes, routinely witness droughts turning into famines even today. Ethiopia faced famine during the 1980s under a dictator and during the early 2000s under a democratic regime. In 2017 and 2018, it again faced the threat of famine. Arguably, the FLSI boom can better explain why famine is history in South Asia. The region is densely plumbed for groundwater-based FLSI, whereas Sub-Saharan Africa has left its groundwater largely untouched. Lipton (2007) found that in India, areas with access to irrigation had 2.5 times lower standard deviation of crop output per year between 1971 and 1984.

FLSI has no doubt created many challenges of sustainable water governance; however, the absence of FLSI revolution in Sub-Saharan Africa should arguably be blamed for recurrence of famine in the region. The 2017–18 drought was one of the worst in 35 years, with 38 million people at risk across eastern and southern Africa (World Bank 2018). Its fallout revealed itself in chronic food insecurity, environmental migration, and civil instability in several Sub-Saharan African countries. Billions of dollars in aid were needed to avert further catastrophe. The event follows similar humanitarian crises in the region, such as in 2011 when 13 million people were directly affected by drought. Given economic water scarcity, even modest departure from normal rainfall turns a drought into a famine in Sub-Saharan Africa, as used to be the case in South Asia for centuries before its groundwater revolution (Shah 2009).

Creative Destruction

An unsavory aspect of the FLSI boom has been that, like a weed, it weakened, marginalized, or crowded out all preexisting irrigation institutions. The private boom in pump irrigation cannibalized traditional community-managed irrigation systems, leaving age-old institutions in ruin and creating new axes of power relations. In the Islamic Republic of Iran, 30,000 to 40,000 *qanats* had performed well since 600 BCE, but the FLSI revolution took a toll on them. In a span of 50 years, most qanats fell into disrepair as landowners reneged on maintenance and repair obligations to invest in groundwater wells (Molle, Shah, and Barker 2003). In inland peninsular India, where agriculture had thrived for millennia on more than 500,000 irrigation tanks and their cascades, the boom in well-irrigation first gave rise to a regime on tank-well conjunctive use. But as density of wells increased, tanks fell into disuse and disrepair as well owners began to renege on their tank-related obligations (Shah and Raju 2001) In the Indo-Gangetic basin, private tubewell revolution forced government tubewells out of business (Shah 1993, 2009).

In Thailand, onset of pump irrigation from government canal systems eroded the long-established system of rotational water deliveries, creating a first-pumped-first-served regime (Molle, Shah, and Barker 2003). In the Nile Delta irrigation system in Egypt, the onslaught of mobile motor pumps disrupted the traditional saquia system of using animal and human labor to lift water from *mesqa* for irrigation, transforming an institution that for long has been "part and parcel of Egyptian landscape and social fabric" (Mehanna, Huntington, and Rachard 1984). In the Mekong Delta in Vietnam, increased supply of boat-mounted pumps for lifting water from channels for irrigation has greatly increased area under irrigated dry crops. This greatly benefitted smallholders but created a new threat during dry years of saline intrusion in the arms of the river and of damage to orchards. A boom in groundwater-based FLSI in Yemen has disrupted an ancient and remarkably efficient regime of terracing and irrigation (Molle, Shah, and Barker 2003). In North China, the private tubewell revolution disrupted a widespread system of groundwater irrigation through collective wells managed by village committees.

A study by Wang, Huang, and Rozelle (2005) showed that in 1983, 93 percent of farmers surveyed used collective irrigation wells; in 1998, only 36 percent did with the rest depending on private wells. In India, countless studies showed that private tubewells and their water-selling business put thousands of government tubewells out of business, weakening the monopoly of canal systems and the power their managers enjoyed over farmers (Shah 2009). Despite the billions that governments and international financial institutions invested in constructing new canal irrigation projects and modernizing old ones, the area served by public canals in India has steadily declined since 1990 (Shah 2009). In Pakistan, for whom the Lower Indus irrigation system has existential significance, private tubewell revolution has meant that increasingly, on-farm water deliveries have relied on tubewells rather than canals (Qureshi 2015).[1]

Note

1. "The expansion of groundwater irrigation in [Pakistan] Punjab registered a 70 percent increase in the irrigated area, from 8.65 Mha in 1960 to 14.7 Mha in 2014 … During the same period, groundwater contribution to overall irrigation water supplies increased from a merely 8 percent to over 60 percent. During the last three decades, 75 percent of the increase in [irrigation] water supplies have come from groundwater exploitation. In the process, the great canal system of the Indus basin has become less of a water delivery mechanism, and more of a groundwater recharge mechanism. In Punjab, for example, canal system contributes about 80 percent of the total groundwater recharge" (Qureshi 2015, 700).

Chapter 5
FLSI Revolution and Water Governance Challenge

By far, the most intractable challenge of unplanned and unregulated expansion in farmer-led smallholder irrigation (FLSI) has been managing the host of groundwater externalities that arise as a result. Large swathes of the Indus basin has witnessed secular decline in groundwater levels (Shah 2009). Similar large-scale groundwater depletion has been a source of much socioecological concern in the North China Plain. The Islamic Republic of Iran, Jordan, Mexico, Morocco, Pakistan Punjab and Sind, and Yemen are all struggling to find ways to arrest secular groundwater depletion driven by pump-driven FLSI. Groundwater depletion in turn has resulted in increased energy footprint of irrigation; because the bulk of the energy used in pump irrigation is diesel or electricity, depletion also deepens the carbon footprint of FSLI. In many arid and semiarid areas, the groundwater being pumped is old and may never recover. Groundwater depletion has caused landslides in many countries and dried up wetlands and stream flows. Sustained groundwater depletion beyond natural recharge rates has resulted in water-quality deterioration.

Throughout the Ganges-Brahmaputra-Meghna basin and elsewhere, excessive groundwater withdrawals are claimed to have some role in mobilizing geogenic contaminants, such as arsenic, fluoride, iron, and uranium. Above all else, falling groundwater levels have threatened long-term sustainability of groundwater-dependent FSLI and the agrarian economy supported by it. Rising pumping costs have strengthened popular demand for energy subsidies to keep FLSI economically viable. Many state governments in India find themselves gridlocked into a power subsidy regime they are unable to wriggle out of; many others sell power to farmers at a subsidized rate without metering. Energy subsidies sustain unsustainable irrigation in western India, the Islamic Republic of Iran, Jordan, Mexico, Morocco, Pakistan, and even China.

There has been growing clamor for effective demand management strategies for water and energy use in FLSI. Administrative regulation, laws, water rights and entitlements, and groundwater demand management by aquifer communities have been tried since the mid-1990s. These have yielded encouraging results in countries with large commercial farmers but are struggling to produce behavioral change in countries dominated by numerous small farmers.

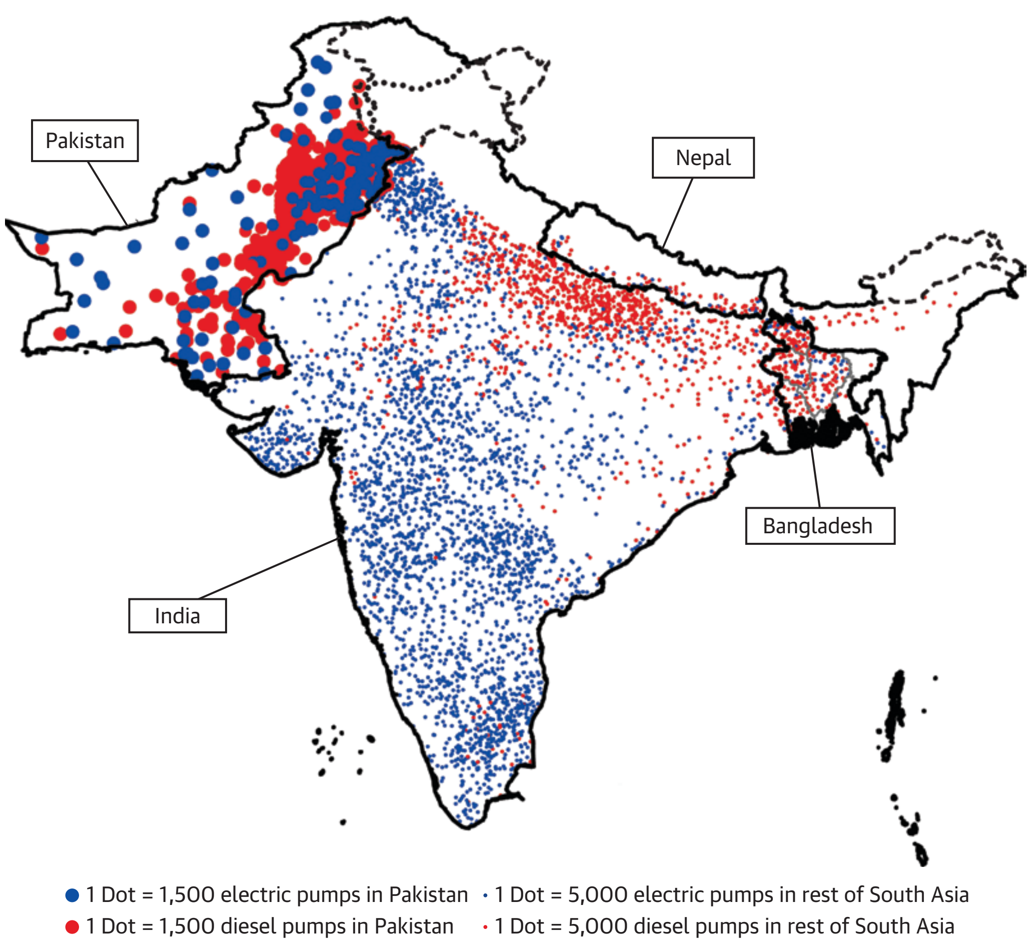
After 2000 many countries have begun trying to tame this runaway anarchy created by FLSI. Many Indian states have separated electricity feeders and rationed power supply to tubewells to cap groundwater draft (Shah et al. 2008). Peninsular India also has witnessed unprecedented initiatives to promote decentralized managed aquifer recharge. China has piloted groundwater allocation to farmers based on available resources and levied penal charges for exceeding the allocated quota. The Islamic Republic of Iran has begun using smart meters to levy a progressive charge for groundwater pumped (Kashi et al. 2016). These are early days, but the wheel of groundwater governance has begun to slowly turn from resource development to resource management mode. Sub-Saharan Africa, however, has far less to worry about large-scale groundwater depletion because of the FLSI boom than Asia and elsewhere in the world for reasons discussed in the next chapter.

Groundwater Depletion in Hard Rock Aquifers: Special Case of Peninsular India and Sub-Saharan Africa

There is, however, a marked difference in farmer behavior between alluvial aquifer areas and hard rock aquifer areas. Much groundwater-dependent FLSI has developed in arid or semiarid (and even humid) alluvial aquifer areas, such as the Indo-Gangetic basin, the Islamic Republic of Iran, Jordan, Mexico, Morocco, the North China Plain, Spain, and Tunisia. In all these landscapes, farmer response to groundwater depletion has been to chase declining water levels, agitate for energy subsidies, and demand import of surface water. There is little evidence of farmer communities undertaking catchment treatment, watershed management, rainwater harvesting, or managed aquifer recharge in alluvial aquifer areas on any significant scale.

However, the scene is different in landscapes with hard rock formations of various kind that have experienced runaway expansion in groundwater-dependent FLSI. The largest continuous such landscape is represented by inland peninsular India, two-thirds of India's landmass. Soon after tubewell irrigation took off in the vast Indo-Gangetic basin, it rapidly spread south. As map 5.1 shows, irrigation wells have proliferated nearly as densely in peninsular India as in the Indo-Gangetic basin. With groundwater

MAP 5.1. Spread of Diesel and Electric Tubewells in South Asia (Circa 2010)

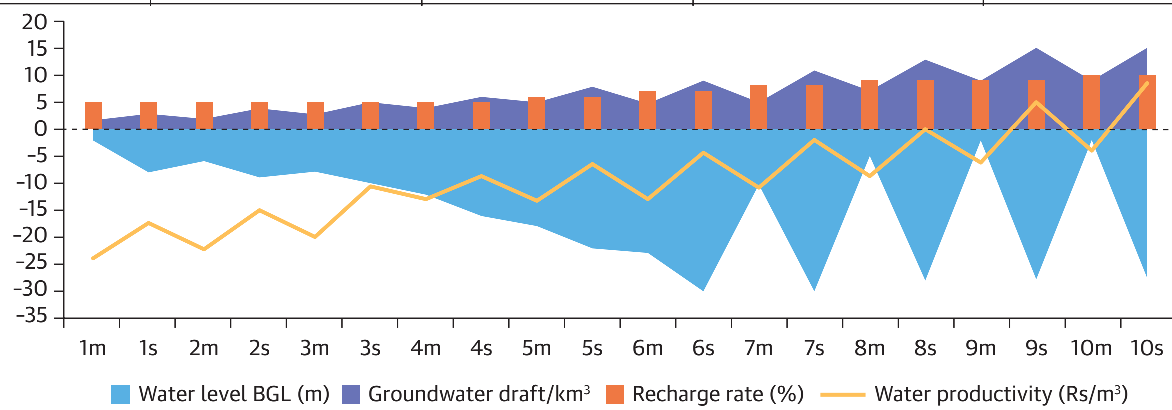


depletion advancing in this landscape, smallholder communities discovered that chasing falling groundwater is often a fruitless strategy in these geological formations where the bulk of the groundwater produced is less than three to five years of natural recharge. Therefore, for more than a decade, they experimented with various ways of prospecting water hidden in large fractures or cavities. Finally, they learned that treating and managing watersheds, constructing check dams, and desilting age-old irrigation tanks and such works increase local groundwater availability. This four-stage progress of rise, decline, and rise again of groundwater-based FLSI in hard rock Saurashtra region of India is caricatured in figure 5.1.

In a comparative study of farmer responses to groundwater depletion in alluvial Punjab and hard rock Telangana states of India, Fishman et al. (2011, 13) noted, "[T]he important role of physical water scarcity as a limiting factor in [hard rock] Telangana and its absence in [alluvial] Punjab... .

FIGURE 5.1. Groundwater-Centric Adaptive Water Resource Management in Hard-Rock Saurashtra Region, India

Stages	I Private Resource Development 1960–75	II Competitive Exploitation 1975–90	III Coping with Interdependence 1987–2010	IV GW-centric Adaptive Water Mgt 2000–2010



Driver of farmer and community behavior	Year-round on-farm water control for intensive farming	Increase dry season on-farm water supply	Augment own and shared GW resource	Adapt to changing GW availability
Observable trends	Motor pump irrigation spreads; innovations in well-boring; drilling costs fall; Economies of scale and scope; water markets emerge;	Competitive deepening; boring within wells; Bores/ha multiply; horizontal bores to augment yield; borewells clustered near water-bodies	Private and community GW recharge; tanks and canals transformed for recharge; support for blanket restrictions on GW draft; demand for micro-irrigation	High value market crops; Demand for micro-irrigation; Demand for public MAR works; Support for watershed mgt; Desilting canals+tanks for MAR
Government policies	Subsidies on motor pumps and boreholes; power subsidies	Pump and bore subsidies continue; half-hearted GW regulation	Watershed management programs; Rationing of farm power supply; Micro-irrigation subsidies	Public Investments in MAR; Inter-basin water transfers; Canal supplies for MAR
Groundwater institutions	Pro-poor buyers' market for irrigation service	Sellers' water market; "moral economy for irrigation"	Irrigation service against 1/4th or 1/3rd crop share	Irrigation for share in high value crops

Source: Developed by author.

Note: BGL = below groundwater level; GW = groundwater; MAR = managed aquifer recharge.

In the dry season annual fluctuations [in Telangana] are largely driven by preseason water tables, and in the rainy season by rainfall. In the deep aquifers of Punjab, in contrast, such short-term fluctuations do not seem to impact irrigation much."

Fishman et al. (2011, 2) concluded:

> In case of groundwater abundance, e.g., in regions with alluvial aquifers [such as Punjab], increases in the use of energy for pumping can make up for the decline in water tables and enable water extraction to be maintained or even increased. ... However, in the shallow aquifers of peninsular India, water itself is limited, and increases in the supply of energy may fail to substitute for the depleting resource. This is precisely what our results demonstrate.

In hard rock thin aquifers of peninsular India, farmers first exhaust all the avenues to enhance recharge and maximize their share in it. When all these potentials are exhausted, grounds become fertile for adaptive self-management of aquifers, surface water bodies, and rainfall in a conjunctive mode (stage IV). A growing movement to convert centuries-old irrigation tanks into recharge tanks in hard rock districts of Andhra Pradesh, Karnataka (Kolar district), Maharashtra, and Telangana (Anantpur and Chittoor districts) is indicative of this trend. India has witnessed many such experiments by communities supported by governments, but all are confined to the so-called thin aquifers. There is no evidence of it in deep (or thick) alluvial aquifers. As van Steenbergen and Shah (2003, 242) noted, "Particularly where the impact of recharge or pumping is immediate and dynamic, self-regulation has developed." Self-regulation can focus on demand-side measures, in which users are restrained from unbridled pumping, or supply-side, in which users are enjoined to contribute to enhance the resource.

By far, the best example of demand-side self-regulation of any significant scale is the Andhra Pradesh farmer managed groundwater systems. A group of nongovernmental organizations (NGOs) has involved farmers from more than 700 villages in overexploited hard rock areas in a program of understanding and monitoring their groundwater resource and planning their agricultural operations, such that they are consistent with the resource regime (van Steenbergen 2010; World Bank 2010). Large-scale construction of more than 2,000 *johads* (ponds) by 550 local communities in the Alwar district of Rajasthan is another example of adaptive aquifer management by farmer communities (van Steenbergen and Shah 2003).[1] Athavale (2003), a senior hydrogeologist, argued that the basis for large-scale build-up of popular support for the *johad* movement was an impervious layer some 30 feet below ground level, which ensured that percolation and infiltration from johads stayed in large part to become available as groundwater in wells.

A mass movement for well recharge and water conservation in the Saurashtra region in Gujarat (India) testifies to farmer communities in hard rock areas responding to groundwater depletion differently from those in arid alluvial aquifer areas. Inspired during the late 1980s, thousands of farmers took to decentralized rainwater harvesting and recharge by modifying their large open wells for receiving filtered floodwaters from rain and constructing small check dams and underground dykes. Impressed by benefits reaped by these pioneer farmers, by the mid-1990s, groundwater recharge turned into a mass social movement with philanthropic support flowing from all directions, including cement factories offering free cement for check dams and diamond merchants from Surat and Brussels paying for

Earth-moving machinery. Some hydrogeologists argued that Saurashtra's hard rock aquifers had too little storage. In fact, limited storage sustained farmer enthusiasm as farmers saw overspilling wells in monsoon rains as a sign of success. During the past 15 years, support to decentralized groundwater recharge structures has become the official policy of Gujarat. By 2008, 113,738 check dams, 55,917 bori bandhs,[2] and 240,199 farm ponds were constructed by communities, in addition to 62,532 large and small check dams constructed by government machinery—all in a campaign mode. Although much of India has been experiencing secular decline in groundwater levels, Saurashtra's groundwater regime has steadily improved as suggested by maps released by India's Central Ground Water Board.

Hard rock peninsular India is now witnessing growing government investment and community participation in decentralized groundwater recharge as a response to overdevelopment of groundwater resource. Chhattisgarh, Maharashtra, Rajasthan, and Telangana have begun implementing an annual routine of pre-monsoon desiltation of tanks, check dams, and percolation ponds with community and NGO participation. Figure 5.1 explains how communities would respond arguably better to full development of groundwater resources in Sub-Saharan Africa than, for example, in Morocco or Indian Punjab.

Notes

1. For example, a PhD thesis for an Australian university (Glendenning 2009) examined the impact of 366 johads in a 476-square-kilometer area and found the average daily potential recharge from rainwater harvesting (RWH) structures was between 12 and 52 millimeters per day, recharge reaching the groundwater was between 3 and 7 millimeters per day, and approximately 7 percent of rainfall is recharged by RWH in the catchment. The analysis showed that as RWH area increases, it reaches a limiting capacity in which developing additional RWH area does not increase the benefit to groundwater stores but substantially reduces streamflow. Nevertheless, RWH in a system increased the overall sustainability of the water demand for irrigated agriculture compared to a system without RWH. Also, RWH provided a slight buffer in the groundwater store when drought occurred.

2. Small check dams constructed with sand bags.

Chapter 6
Why Can Sub-Saharan Africa Sustain an FLSI Revolution Better than South Asia?

Sub-Saharan Africa is better placed for groundwater irrigation than peninsular India. It is better endowed with groundwater and has a far smaller farming area to irrigate. Yet for a long time, scientific opinion favored a precautionary approach towards groundwater development for irrigation. The dominant view was that as a strategic buffer, groundwater should be prioritized for urban and rural drinking water supply. Unlike the prolific aquifer system of the Indo-Gangetic basin, which became the poster child for the global groundwater boom, much of Sub-Saharan Africa is dry or semiarid and has hard rock aquifers with limited storage. Failure of drinking water hand pumps and urban groundwater decline were often used to justify this excessively precautionary outlook.

More recent assessments after 2010 by leading hydrogeologists, however, paint a far more positive outlook of groundwater resources of Sub-Saharan Africa and commend accelerated use of groundwater for smallholder livelihoods, of course with the usual caveats and emphasis on better information and resource monitoring. The region is estimated to have 1,400 cubic kilometers of renewable shallow groundwater resource, nearly three times that of all of South Asia and more than 12 times more than peninsular India (which has a hydrogeological profile closer to Sub-Saharan Africa than the Indo-Gangetic basin that accounts for much of South Asia's groundwater resource).

Sub-Saharan Africa has vastly larger nonrenewable deep groundwater, some 660,000 cubic kilometers,[1] which is costlier to develop, energy intensive to use, and, therefore, more suited for municipal demand and large-scale commercial farming than for farmer-led smallholder irrigation (FLSI) development (MacDonald et al. 2012). The subcontinent uses about only 2 percent of its internally renewable groundwater resource, defined as the total amount of recharge received by its combined aquifers. A World Bank (2018) report estimates that even in Sub-Saharan Africa's dry regions, which compose 40 percent of its land mass, houses 64 percent of its population, has plentiful groundwater accessible at 25 meters or less, and receives annual natural recharge of 20 millimeters. Groundwater irrigates only 0.4 meters per hectare in Sub-Saharan Africa.[2] But even when environmental requirements are considered, the region has enough shallow groundwater to irrigate between 44.5 million hectares and 105.3 million hectares (Altchenko and Villholth 2015). Pavelic et al. (2013) suggested that in the 13 Sub-Saharan Africa countries they studied, known groundwater resource can easily support 120 times their current groundwater-irrigated area.

All in all, as the World Bank (2018) report concluded, "Local availability, ubiquity protection from pollution and cost effective, easy, quick and incremental development potential; large storage volumes and protection from evaporation make groundwater a strategic asset in adapting to climate change impacts." Sub-Saharan Africa has 10 times more renewable groundwater compared with peninsular India and 10 percent of its landmass under cultivation versus more than 75 percent in peninsular India, thanks to the latter's dense population. Even with such favorable per capita resource availability, there still lurk risks of pockets of overdevelopment, especially in concentrated urban demand or large commercial farms. Distributed growth in smallholder irrigation with small pumps may be less of a cause for concern, if preceded by proper hydrogeological investigation and accompanied by watershed treatment *pari passu* with groundwater development.

Notes

1. This is equivalent to more than 7,000 years of average total flow of the Nile River (World Bank 2018).

2. Many people, however, argue that this is a gross underestimate. Giordano (2006) argued that groundwater-irrigated area in Sub-Saharan Africa has already grown to between 1 million hectares and 2 million hectares with Ethiopia having 100,000 lift-irrigated hectares and Ghana 190,000 hectares. According to Villholth (2013), Siebert et al. (2010) estimated groundwater-irrigated area of Sub-Saharan Africa to be 328,500 hectares (6 percent of total irrigated area of 5.44 million hectares). However, her own estimates based on a later exercise placed groundwater at 1,248,800 hectares (20 percent of a total irrigated area of 6.356 million hectares).

Chapter 7
Supporting Accelerated FLSI Growth in Sub-Saharan Africa

Such farmer-led smallholder irrigation (FLSI) expansion as Sub-Saharan Africa has witnessed so far is largely a *laissez faire* phenomenon with governments and donors taking a hands-off approach. FLSI will continue to grow in this format but at a far slower pace and inequitable manner than is needed to bring about rapid and equitable growth in smallholder agriculture. Governments in South Asia and elsewhere have been far more active in accelerating FLSI, including with support from agencies such as the World Bank. Although Sub-Saharan Africa will chart its own course for growing FLSI at a rate commensurate with its agricultural growth ambition, some key lessons from Asia and elsewhere might be relevant in thinking about a more aggressive and proactive program to accelerate the pace.

- *Proactive government promotion:* Global experience shows that governments played a proactive role in promoting FLSI. Without government involvement, FLSI would be adopted and captured by the elite, as is already the case in Sub-Saharan Africa (Namara et al. 2013, Shah, Verma, and Pavelic 2013). In India, governments invested for 50 years before FLSI by resource-poor farmers took off. For millions of Sub-Saharan African smallholders, benefits of modern FLSI are still to be demonstrated and persuaded. In this respect, the importance of government initiative in FLSI promotion cannot be overemphasized. Most Sub-Saharan African governments still turn a blind eye to FLSI today. Chokkakula and Giordano (2013) found that most do not have even a policy for promoting groundwater irrigation among smallholders. If Sub-Saharan Africa is to have a broad-based FLSI boom, a proactive stance from governments and donors is needed.
- *Shedding precautionary excess:* A powerful barrier to proactive government policy is a deeply ingrained view that Sub-Saharan Africa has little groundwater and whatever it has is best reserved for drinking-water needs. Elsewhere, policy makers and local hydrogeologists viewed groundwater as a resource to be prospected, developed, and used to reduce poverty and hunger by promoting the Green Revolution. The global environment movement was in its infancy, and the key concern of researchers during the 1980s was equity in poor people's access to groundwater, which "water lords" had a tendency to monopolize (see, for example, Chambers, Saxena, and Shah 1989; Dhawan 1982). However, global environmental debate and Integrated Water Resources Management (IWRM) have bred a precautionary excess in the Sub-Saharan African mind-set about groundwater irrigation when it has hardly begun to develop it groundwater resource. Global assessments strengthened this view. A few years ago, a World Bank paper wondered "whether accelerating groundwater irrigated agriculture [in Sub-Saharan Africa] from the existing 0.4 million hectares to beyond 1 or even 2 million hectares is possible," when peninsular India, a smaller landscape with more modest groundwater resources, has 18 million hectares under groundwater irrigation. The paper further cautioned that "consideration needs to be given as to whether this is technically realistic and economically feasible" (Tuinhoff et al. 2011). Chokkakula and Giordano (2013) argued that excessive focus on groundwater regulation

under the guise of IWRM philosophy is to blame for the absence of government support and enthusiasm for pump-driven FLSI. This precautionary excess seems unjustified given the vastness of Sub-Saharan Africa's groundwater resource and modest volumes needed to vastly improve livelihoods of its sparse peasantry.

- *Devising smart incentives:* Sub-Saharan African governments need to design and offer smart incentives/subsidies to be withdrawn when they serve their purpose. Compared to committing resources to large canal irrigation projects, incentivizing private investments in FLSI will arguably be cheaper, more efficient, and more equitable. Sub-Saharan Africa should certainly begin by liberalizing imports of pumps and pipes. However, more aggressive initiatives will be needed to create a demand pull and achieve a critical mass before mechanized FLSI can take off. Nongovernmental organizations (NGOs) and donors have also overdone manual irrigation and miniature motor pumps—what one researcher called Mickey Mouse irrigation—targeted to kitchen gardens. However, other options need to be explored to accelerate FLSI development (Burney and Naylor 2012). There are already examples of village entrepreneurs selling pump irrigation service (de Fraiture and Clayton 2012), for which there is strong economic demand. Catalyzing such markets can improve the economic viability of FLSI investments by raising their operating factor and making piped irrigation affordable to neighboring smallholders.
- *Affordable FLSI:* An important reason pump-driven FLSI is slow to take off in Sub-Saharan Africa is high cost of equipment and boring. The market is largely driven by donor funding and international NGOs, who generally depend upon first-world companies with high-quality products offered at prices beyond the reach of Sub-Saharan Africa's smallholders. The small motor pump market in Sub-Saharan Africa involves small volumes and high margins, but throughout Asia, FLSI boomed because of large volumes and low margins in the motor pump and drilling services market. The FLSI boom in Bangladesh and Vietnam was initially fueled by used Chinese pumps available at US$10 to US$15 apiece and borings that cost next to nothing. Sub-Saharan African farmers need to be given the option to choose between high quality at high price and lower-quality products at prices they can afford. This is already happening as Chinese and Indian entrepreneurs enter Sub-Saharan Africa with affordable FLSI options.[1]
- *Generating demand pull for critical mass:* Experience of North China and South Asia validate the notion that irrigation is a leading input in agricultural transformation. Many scholars bemoan that FLSI has failed to take off in Sub-Saharan Africa because rainfed farming runs deep in local culture; input and output markets are poor; transport is expensive; fertilizer use is low; tenure is insecure; and institutional credit is hard to come by. Asian experience suggests that once critical mass in mechanized FLSI is reached, demand pull by smallholders tends to ease many of these constraints and provide a "lift" to the smallholder farm economy.[2] Fertilizer use in India soared after tubewell revolution, not before. Despite constraints of fragmented landholdings, a large number of seasonal tenant farmers without tenure security, poor roads, and a lack of electricity, Bangladesh became a rice exporter after the shallow tubewell boom. If Sub-Saharan Africa can step up expansion of mechanized FLSI from its tepid rate of 60,000 hectares per year to a rate that a small country like Bangladesh

achieved between 1985 and 1995, the sheer momentum may alleviate many constraints that impede growth in smallholder-irrigated agriculture. Volume begets savings; Sub-Saharan Africa's current low-volume-high-margin FLSI market needs to be transformed into a high-volume-low-margin one. Burney and Naylor (2012) found similar evidence in Benin: "A project combining access, distribution and use [of irrigation water] can have high returns in the short run, including at the institutional level—potentially becoming a 'game changer' for agricultural development over time" (121) and later concluded that "well-designed irrigation technologies can generate income, promote food security, bridge institutional gaps, and bolster local institutions" (122). Critical mass in mechanized FLSI will unleash economies of scale and scope that reduce the cost of FLSI.

- *Piloting alternative institutional models for FLSI:* Globally, and particularly in Asia, several institutional models with varying levels of government (versus people's) involvement have been tried to promote mechanized FLSI. By far, the most dominant involves FLSI owned by individuals for their own irrigation needs and supplying neighboring farmers for a fee. Arguably, more than 90 percent of global FLSI falls in this category. On the other extreme is the example of the Barind Multipurpose Development Authority (BMDA) in northwestern Bangladesh, which owns and operates more than 15,000 irrigation tubewells to supply irrigation to farmers on a full cost-recovery basis. The BMDA is management intensive but has the advantage of undertaking groundwater recharge projects—thus, it also serves as a groundwater governance agency. China's village committee-managed tubewells could have played a similar resource governance role but have increasingly lost their custom to private tubewells. Botswana has decades-old institution of borehole syndicates as an institutional model for cooperative management of groundwater assets by cattle herders (Closas and Molle 2016). India's state-level tubewell corporations too could have assumed a resource governance role, but they have all become defunct as farmers turned wholesale to private water markets. Although public tubewells throughout India failed, Gujarat turned more than 3,500 heavy-duty tubewells to farmer groups on annual rental, which are still financially sustainable (Mukherji and Kishore 2003). Supporting young men and women farmers to operate motor pump irrigation systems as entrepreneurial irrigation service providers selling irrigation service to neighboring farmers, as is already happening in many parts of Sub-Saharan Africa (see de Fraiture and Clayton 2012), can expand reliable irrigation and create new livelihoods.

Notes

1. In 2016, some 700 drilling rigs were operated by 150 Indian companies set up by entrepreneurs from Gujarat, Kerala, Tamil Nadu, and Telangana in 21 Sub-Saharan African countries offering drilling service at a 15 to 20 percent higher price than in India but at much lower than international costs (Karnakar Reddy 2016).
2. Following Boyce (1987), a dominant strand of thought that shaped government's agricultural policy was that Bangladesh's agrarian impasse was caused by its agrarian structure—extreme land fragmentation, feudal culture, risk aversion generated by flood-proneness, poor market linkages, and lack of infrastructure. The Bangladesh Agricultural Development Corporation was pursuing a maximalist approach working on all these constraints simultaneously. Eventually a minimalist intervention—of just allowing free imports of pumps and pipes—unleashed FLSI and accelerated agricultural growth (Palmer-Jones 1989).

Chapter 8
Solar Pump Irrigation: Sub-Saharan Africa's Opportunity for Leapfrogging?

A major disruption in the global farmer-led smallholder irrigation (FLSI) scene is likely to come from declining costs and growing popularity of solar irrigation pumps (SIPs). SIPs have been on trial for decades but are now getting mainstreamed. They are high on capital cost, but once installed, they operate at a near-zero operating cost, which is a great advantage for smallholders for whom the high overall cost of fetching and using diesel or petrol often poses a big barrier (Shah et al. 2008).

Governments are once again at the forefront in promoting SIPs among smallholders. India, whose energy economy has been struggling under the deadweight of farm power subsidies, has promoted solar pumps aggressively to save power subsidies in western parts and to provide smallholders with an affordable alternative to diesel pump irrigation. From fewer than 1,000 in 2012, SIP numbers in India crossed 180,000 in 2018. Throughout Bangladesh, eastern India, and Nepal terai, where FLSI depends on diesel because of lack of electricity, there is strong demand pull among farmers for solar pumps.

Like many nongovernmental organizations (NGOs) and donors in Sub-Saharan Africa, governments are promoting miniature solar pumps of 0.1 to 2 kilowatt-peaks for garden irrigation. The objective is to demonstrate solar technology and spread limited subsidy funds over a large number of smallholders. However, it is increasingly being recognized that right-sized SIPs (that is, 3.5 to 5 kilowatt-peaks) can play a far bigger irrigation role by creating pro-poor irrigation service markets. The government of Bangladesh is assisting entrepreneurs in operating SIPs for the express purpose of selling irrigation service to farmers nearby. Bihar is turning young entrepreneurial small farmers into solar irrigation service providers to create pro-poor irrigation service markets.[1]

SIPs are a godsend for Sub-Saharan Africa and can be the foundation of its FLSI development strategy. Even if Sub-Saharan Africa accelerated motor pump availability among smallholders, capital scarcity coupled with the high cost of diesel/petrol would be a major constraint for FLSI expansion.[2] SIPs liberate pump-driven FLSI from this powerful constraint of high-energy cost. Because they are simpler to operate and need less maintenance, chances are that women farmers will take to SIPs more easily than diesel/petrol pumps, although the jury is out on this proposition. IWMI research on solar pump suitability mapping in Ethiopia and elsewhere in Sub-Saharan Africa shows large swathes with abundant solar irradiation and local availability of shallow groundwater or small reservoirs establishing technical feasibility of widespread solar FLSI (Smitter et al. 2018).

SIPs' initial capital investment may be a deterrent; however, when volumes are large, SIP costs are dropping precipitously. In India, SIP (panels, pumps, invertor, and meters) costs were more than US$1,500 to US$1,700/kWp in 2015. However, in early 2018, Gujarat started a SIP scheme in which costs are capped at US$850 per kilowatt-peak (excluding pumps). Sub-Saharan Africa should also experiment with alternative techno-institutional models of SIP irrigation—including mini-SIPs[3] popular with NGOs; mobile, cart-mounted SIPS; solar irrigation service-providing entrepreneurs; and others and choose what is best suited to its specific conditions on criteria like area irrigated per installed kilowatt-peak, annual operating hours, power availability on peak irrigation days, and so on.

One challenge in making SIPs viable is finding an attractive market for solar energy outside irrigation seasons. In South Asia, irrigation use for a SIP is 700 to 1,100 hours, but it can operate for 2,500 hours or more per year. Gujarat has just launched a scheme called Surya-shakti Kisan Yojana (SKY) to connect solar pumps to the grid and buy surplus solar power from farmers after they are done with irrigation. In this context, the role that SIP clusters can play in the larger scheme of rural electrification needs to be explored. In Sub-Saharan Africa, 599 million rural people are without access to electricity (Okoye and Oranekwu-Okoye 2018), and SIPs can help by improving the viability of electricity network investments. Solar mini-grids are an option but still expensive because they need batteries. Integrating SIPs into a rural grid can be a competitive alternative.

In India, serving electricity to rural homes was the original purpose for promoting tubewells. William Stampe, a maverick colonial engineer, persuaded the government in the 1920s to install hydroelectric generation stations in the Ganga Canal to supply electricity to rural homes and rice mills. However, he was worried about insufficient baseload of domestic users. To make the proposal viable, he proposed tubewells to irrigate uplying areas not commanded by the distributaries of the Ganga Canal. According to Subramanian (2015), the Ganges grid executed by Sir William Stampe uppended conventional thinking about rural electrification. The Ganges grid was designed primarily for irrigation; providing power for other purposes was secondary. It was to expand the tubewell program that the grid quadrupled its capacity and also added a thermal plant. The thermal plant (unlike hydropower plant on canals) could by no means be justified as irrigation expense had irrigation not been primary load. In 1939, half of the grid's revenues were from power sales to irrigation pumps, even when supplied at subsidized rates. It was thus tubewell irrigation that made rural electrification viable.

Stampe's scheme and his Ganges grid fell by the wayside, but tubewells survived, flourished, and multiplied in the following years. Stampe's logic is relevant to rural electrification of Sub-Saharan Africa—SIP clusters can play a similar role in improving the viability of Sub-Saharan Africa's rural power networks. Laying an electricity network to supply miniscule rural domestic loads is financially unviable, but if the same network is used to buy surplus off-season solar power from farmers, SIPs can increase the economic viability of both the network and the solar pumps, in addition to incentivizing judicious use of free solar energy to support a booming FLSI economy.

Notes

1. In a pilot project in the water-abundant Bihar state, the International Water Management Institute (IWMI)/the CGIAR Research Program on Climate Change, Agriculture and Food Security enabled six young farmers in the Chakhaji village to buy 5-kilowatt-peak solar pumps and 1,500 feet of buried pipe distribution system to irrigate their own land and sell irrigation service to other farmers in the village. The objective of the pilot was to test whether SIPs can transform a monopolistic water market dependent on diesel pumps into a pro-poor one (ITP 2017; Kumar and Goel 2018; Rai 2018). As expected, solar irrigation service providers effectively reduced water price to one-third of what prevailed before and expanded irrigation demand by 2.5 times, growing Chakhaji's agricultural gross domestic product 70 percent in 18 months. As a spillover, six young farmers got full-time jobs as water sellers. The government of Bihar is scaling up this pilot to 100 villages before taking it statewide.

2. A 2011 IWMI survey of 1,550 farmers from 11 Sub-Saharan African countries found the high cost of fuel to run motor pumps was mentioned by respondents as a "severe" constraint and will check the pace of pump-driven FLSI in Sub-Saharan Africa. Carter and Howsam (1994) noted that cheap petrol-driving irrigation pumps drove away the *shaduf* in Nigeria during the 1970s and 1980s but that rising petrol prices may bring the shaduf back. High and rising fuel prices may check the pace with which Sub-Saharan African smallholders are able to move from manual to mechanical pumps.

3. Sunflower solar pumps being piloted in several Sub-Saharan African countries use a 70- to 80-watt solar panel and can lift 2 cubic meters per hour at 1-meter groundwater depth or 0.9 cubic meters per hectare at 6-meter groundwater depth. This is good for a small kitchen garden and livestock watering but would be too small for half an acre of tomato.

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