Innovations in Agricultural Groundwater Management:

Examples from India

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Abstract. This review paper attempts to do three things. First, it provides an overview of the global groundwater economy and explores the nature, drivers and characteristics of agricultural groundwater use in four distinct parts of the world, viz., the MENA region, the industrialized world, in sub Saharan Africa and in monsoon Asia. Second, the paper provides a brief review of instruments of groundwater governance that have been tried in different parts of the world, and examines their potential relevance for South Asia which dominates global agricultural groundwater use. The instruments reviewed include: administrative and legislative regulation; economic instruments; tradable property rights, community management of aquifers, and crowding out tubewells through imported surface water. Third, the paper explores some unconventional ideas that have been tried in South Asia to regulate groundwater use in this region's unique socio- ecological and political context.

1. GROUNDWATER AND GLOBAL AGRICULTURE

Rapid growth in groundwater use is a central aspect of the world's water story, especially since 1950. Shallow wells and muscle-driven lifting devices have been in vogue in many parts of the world for the millennia. In British India (which included today's India, Pakistan and Bangladesh), wells accounted for over 30 percent of irrigated land even in 1903 when only 14 percent of cropped area was irrigated[1]. With the rise of the tubewell and pump technology, groundwater use soared to previously unthinkable levels after 1950. In Spain, groundwater use increased from 2 km^3/year to 6 km^3 during 1960-2000 before it stabilized (Martinez Cortina and Hernandez-Mora 2003). In the US, groundwater share in irrigation has increased, from 23 percent in 1950 to 42 percent in 2000[2]. In the Indian sub-continent, groundwater use soared from around 10-20 km^3 before 1950 to 240-260 km^3 today. Data on groundwater use are scarce; however, figure 1 attempts to backcast the probable trajectories of growth in groundwater use in selected countries. While in the US, Spain, Mexico, and North-African countries like Morocco and Tunisia total groundwater use peaked during 1980's or thereabouts, in South Asia and North China plains, the upward trend begun during the 1970s is still continuing. A third wave of growth in groundwater use is likely in the making in many regions of Africa and in some south and south-east Asian countries such as Vietnam and Sri Lanka.

Clearly, until 50 years ago, groundwater's role in agriculture was insignificant in much of today's developing world. But today, the situation is vastly different. Table 1 provides a recent global estimate of irrigated areas in different parts of the world and the share of groundwater in irrigated area. This shows that over 1/3rd of the world's irrigated area of 303 m ha is served by

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[1] http://dsal.uchicago.edu/statistics/1894_excel

[2] http://water.usgs.gov/ pubs/circ/2004/circ1268/

groundwater. FAO estimates are based on figures provided by governments of member states. And in South Asia, it is common knowledge that groundwater irrigated areas are seriously underestimated and surface irrigated areas, seriously over-estimated. The same is the situation in China, another major groundwater irrigating country, where estimates of groundwater irrigated area are being constantly revised upwards (Shah 2009). As more research results become available, it is getting clear that in much of Africa too, informal groundwater irrigation in the private sector is booming while many public irrigation systems are stagnant (Giordano 2006). In actual terms, then groundwater is likely even more important in global agriculture today than FAO numbers suggest.

2. STRUCTURE OF THE GLOBAL GROUNDWATER ECONOMY

While groundwater use in agriculture is growing around the world, the drivers of this growth are different in different parts with different implications on resource productivity and governance regimes. For a long time, water scientists believed that groundwater irrigation would intensify only in arid or semi-arid areas of the world like California which, except for shortage of rainfall and surface water, are otherwise ideal for agriculture. But booming groundwater irrigation in humid Bangladesh and eastern India puts paid to this argument. Many scientists also thought that intensive groundwater irrigation will sustain only in alluvial aquifers that are constantly recharged by floods (e.g., Ganga basin) or canal irrigation (e.g., Indus Basin Irrigation System) and not in hard rock aquifers with low storage and yield. But rapid expansion of groundwater irrigation hard rock peninsular India defies this hypothesis. Henry Vaux has argued that ‘sustained depletion of groundwater aquifers is self-terminating’ because rising pumping costs would make groundwater use unsustainable. However, such depletion has been sustained in

South Asia and Mexico by farmers organizing into powerful political interest groups to extract power subsidies for groundwater pumping (Shah 2009). All in all, groundwater irrigation dynamic varies around the world in keeping with the changing socio-ecological context.

Four broad types of global groundwater socio-ecologies can be identified around the world as in table 2: arid agrarian systems, industrial agricultural systems, groundwater-supported extensive pastoralism, and smallholder intensive farming systems. These differ from one another in their overall climatic, hydrologic, and demographic parameters, their land-use patterns, their organization of agriculture, and the relative importance of irrigated and rain-fed farming. Also different are the drivers of expansion in groundwater irrigation in these areas and the nature and level of these societies' stake in their groundwater-irrigated agriculture.

In the mostly arid countries of MENA regions, water scarcity is the key driver of groundwater irrigation. The challenge here is of striking the balance between present versus future use and irrigation versus urban uses of what is mostly non-renewable fossil groundwater. Even industrialized countries – such as Spain, Italy, United States and Australia-- groundwater in some areas suffer from depletion as well as pollution from agriculture, but it supports high value export agriculture. These countries bring together vast financial and scientific resources to agricultural groundwater management; as a result, it is here that much of today's scientific and institutional knowledge base for groundwater management has evolved and has been tested . In sub Saharan Africa and Latin America agricultural groundwater use is small not only in absolute terms but also in relation to available (known) potential. However, groundwater is becoming increasingly significant for supporting small holder agriculture and the livestock economy that supports millions of poor people in Sub-Saharan Africa. In none of these three regions, however, is the groundwater dynamic as complex and overwhelming as in smallholder intensive farming system of monsoon Asia. Explosive growth in agricultural groundwater use in South Asia and China is driven less by water scarcity and more by land scarcity, making it imperative for small-holders to intensify their land use to protect their livelihoods. India, Pakistan, Bangladesh, Nepal and China likely account for over 70% of global annual groundwater diversion of around 1,000 cubic km; and it is here that some of the worst consequences of groundwater overdraft are visible in large and growing pockets. The rise of water-scavenging atomistic irrigation by millions of private tubewell owners defines the resource management challenge here. True, supply-side factors, such as government subsidies for pumps and electricity, helped promote intensive groundwater irrigation, but the primary driver is the rise in population pressure on farmland, which has made intensive diversification a precondition for smallholder subsistence—something unlikely ever to occur in the other three socio-ecologies.

In all the four groundwater socio-ecologies, a variety of environmental and economic externalities associated with groundwater intensification are observed in some pockets. In the Smallholder Intensive Farming Systems, however, these externalities are a norm rather than exception and encompass vast areas. The most common is depletion of alluvial as well as hard rock aquifers signified by secular decline in groundwater levels. This in turn gives rise to soaring pumping costs, increasing investments required in installing new tubewells, interference among wells, and so on. Also evident on a large scale are other symptoms: drying up of wetlands, declining low-flows in rivers and streams, secondary salinization and increase in the concentration of geogenic contaminants such as fluoride, arsenic and nitrates in groundwater which is the main source of drinking water supplies. Flourosis and arsenicosis are considered major public health risks in large areas of South Asia and China. All these externalities have put into bold relief urgent need to put into place a groundwater governance regime that minimizes ill-effects while sustaining the massive poverty-reduction benefits that groundwater boom has produced in Asia.

Groundwater governance discourse worldwide is a product of the growing threat of water scarcity, which has made the transition from resource development to resource management mode critical. In this transition, groundwater—an invisible, fungible resource—has proved particularly difficult, and although the western United States, Spain, Mexico, and other countries offer lessons about attempts to craft groundwater governance regimes, nowhere are the outcomes fully satisfactory. However, as the groundwater question becomes more pressing, South Asian policymakers must understand what has been tried elsewhere and ask what has (or has not) worked and why (or why not). To this end, the following sections briefly review the experience with five major groundwater governance instruments, each of which seeks to directly influence the actions and behavior of users.

3. INSTRUMENTS OF GROUNDWATER GOVERNANCE:

3.1. Administrative Regulation**.** Governments in many countries, notably Oman, Iran, Saudi Arabia, Israel and countries in South Asia have often use laws and administrative regulation to control agricultural groundwater draft. These have worked where the state is strong-even authoritarian-- and the number of groundwater users is small, as in Oman. However, almost everywhere else, administrative regulation of agricultural groundwater use has been generally poor because of lack of three essentials: popular support, political will and enforcement capacity.

3.2. <u>Economic instruments</u>**.** Using a price or a Pigovian tax is generally considered superior method of influencing human behavior than using coercion or invoking eminent domain. In the Western US, a pump tax was widely used to control groundwater overdraft. In Israel, water pricing is effectively used for groundwater demand management; and in China, pricing has been important in managing urban groundwater demand. Pricing works best when it is easy to measure and monitor groundwater abstractions, that is where abstractors are few and large. Where groundwater abstractors are small, numerous and poor, groundwater pricing becomes difficult to administer without awkward use of force. Jordan had to create a water police to install meters on deep tubewells and enforce pricing. As a result, while the principle of "scarcity pricing" is widely accepted, its actual practice has proved difficult in the developing world.

3.3 <u>Tradable property rights</u>. In the New World countries like US and Australia, secure property rights were essential to encourage settlers to make private investment in land and water development during 18th and 19th centuries. Groundwater governance in these countries is based on the premise that users *can* evolve regimes for self-governance of water resource with the state providing an overarching regulatory and facilitative framework. The institution of tradable property rights in water is the basis for such self-governance. The experience of the US has given birth to a growth industry for promoting tradable water rights as a one-stop solution problems of groundwater malgovernance. The ultimate result of creating tradable rights in groundwater, however, is by no means clear in the US or elsewhere. The impact of introducing tradable water rights in Chile has been vigorously lauded as well as roundly criticized. As with pricing, with tradable property rights, too, there is no gainsaying the principle that these can result in superior allocation of scarce groundwater. The real problem is the transaction cost of enforcement which rise in geometric progression with the number of users. Because transaction costs matter, groundwater institutions in the US and Australia carefully exempt numerous *de minimis* users to reduce transaction cost of institutional management of groundwater to manageable levels. However, if India or China were to exempt *de minimis* users that are exempted say in Kansas, Nebraska, and Australia, more than 95 percent of groundwater users would fall through the sieve.

3.4 Community aquifer management. Mexico and Spain have adapted the U.S. experience of tradable water rights and groundwater districts to promote groundwater management through farmers' organizations. Spain's 1985 water act made basin level groundwater federations responsible for resource planning and management. Similarly, Mexico's 1992 Law of the Nation's Water created Aquifer management councils, known as COTAS, for groundwater management. While the idea has great merit, the implementation of this mandate has proved difficult in Spain as well as Mexico. While Mexican COTAS have played a useful role in information generation and farmers' education, the effectiveness in managing groundwater overdraft has been poor.

3.5 Crowding out tube wells through supply augmentation. Instead of demand-management, developing alternative water sources has been one of the most effective and time tested approaches for easing agricultural pressure on stressed aquifers. In the Western U.S., imported surface water supplied in lieu of groundwater pumping has been a central feature of groundwater governance for decades. The Central Arizona approach is one example; but there are many other federally supported projects that import surface water to ease pressure on and/or recharge groundwater aquifers. Spain's much-proposed water transfer project from Ebro River, China's south-to-north water transfer project and India's proposed project to link Himalayan with peninsular rivers are all inspired in part by groundwater depletion and stress. The fact that the supply side initiative is used more widely signifies the huge implementation difficulties in direct demand side groundwater management in developing countries.

4. GROUNDWATER GOVERNANCE IN SMALLHOLDER INTENSIVE AGRICULTURE SYSTEMS

Can a groundwater cess or a system of groundwater entitlements or a powerful groundwater law restore order in South Asia's irrigation economy? In theory, yes. The problem is how to make any or all of these actually work on the ground, given the atomistic nature of the subcontinent's irrigation economy. In Mexico, Spain, and even the United States, according to their own researchers, practice has defeated the precept, even though their groundwater economies are much smaller and simpler than South Asia's. Consider the organization of groundwater economies of the six countries listed in Table 3, with India on one extreme and the United States on the other. Indian farmers withdraw around 230 billion m^3 of groundwater annually, more than twice as much as the U.S. users do. But India has 100 times more independent diverters of groundwater. In addition more than half of all Indians—compared with less than 2 percent of Americans—will proactively oppose or frustrate any groundwater governance regime that hits their livelihoods. We know that transaction costs of groundwater regulation are determined less by the volume of groundwater used but more by the number of independent users involved in groundwater irrigation.

The Murray Darling basin in Australia is widely acclaimed worldwide as a water governance exemplar. Yet, governing groundwater has challenged Australian water managers; and the Australian Groundwater School at Adelaide says, “Groundwater will be the enduring gauge of this generation’s intelligence in water and land management.” Many South Asian water country policy makers are hopelessly attracted to the Murray-Darling model but overlook the differences between the Australian and South Asian groundwater economies. Just 5.5 percent of Australia’s irrigated area depends on groundwater compared with more than 60 percent in India and 90 percent in Bangladesh. The 285 to 300 km^3 of groundwater that South Asia withdraws every year to water crops is 50 times what Australia uses. But most importantly, South Asia has 20 million groundwater diverters—5,000 times more people to whom groundwater governance must speak.

China is discovering the implementation challenge of demand management in a vast and atomistic groundwater economy. Just issuing water withdrawal permits to some 7.5 million tube well owners is a logistical nightmare, let alone monitoring their withdrawals. Not surprisingly, Wang et al. (2007, 53), who recently surveyed 448 villages and 126 townships from 60 counties in Inner Mongolia, Hebei, Henan, Liaoning, Shaanxi, and Shanxi, found that

> “inside China’s villages few regulations have had any effect … despite the nearly universal regulation that requires the use of a permit for drilling a well, less than 10% of the well

> owners surveyed obtained one before drilling. Only 5% of villages surveyed believed their drilling decisions needed to consider spacing decisions … Even more telling was that water extraction was not charged in any village; there were no physical limits put on well owners. In fact, it is safe to say that in most villages in China, groundwater resources are almost completely unregulated."

5. GROUNDWATER MANAGEMENT INNOVATIONS IN INDIA:

In many countries, especially in India, groundwater over-draft is in effect state-sanctioned. During 1935-65, governments and international donors were concentrating all their efforts and resources to get reluctant farmers to irrigate with groundwater. Rural electrification investments were justified on the potential that groundwater offered for agricultural growth. State governments established, and the World Bank funded, large public tubewell programs to provide subsidized groundwater irrigation to farmers. Eventually, when farmers began taking to groundwater irrigation in a big way around 1970, governments offered other incentives: liberal electricity connections, low electricity tariffs, subsidy on irrigation equipment. These seemed justified when groundwater-led Green Revolution staved off the prospects of a famine. These also seemed justified because subsidized canal irrigation seemed like a huge fraud on rainfed areas; and subsidizing groundwater irrigation in rainfed areas had an equalizing impact of sorts. By mid-1980's, groundwater irrigation was pervasive and well-entrenched in most of India as were the subsidies that came with it. The most important of these was electricity subsidy. Until 1970, subsidized tariff was collected on a volumetric basis from metered tubewell connections. But the electricity companies found the transaction costs of metering farm power supply too high compared to the amount to be collected. Therefore, most Indian state electricity companies switched from metered tariff to a flat tariff linked to the horsepower of pumps during 1970's and '80's. Around this time, politicians also figured out the political clout of groundwater irrigators and began to use farm power pricing and supply as a tool to galvanize them as a 'vote-bank'. Some chief ministers won elections by offering free power to farmers; others refused to raise flat power tariff for decades, fearing they would lose farmer support.

The original idea of moving from metered tariff to flat tariff had a logic. The cost of metering millions of tubewells scattered in a vast country side was high; the cost of reading meters, issuing bills, recovering dues were high too. Moreover, metering created incentives to pilfer and to manipulate meters which raised the cost of meter maintenance. On the other hand, farmers' demand for power was derived demand for water; they did not need power 24*7 like domestic and industrial consumers; they could meet their irrigation demand as long as they got a few hours of power supply every day. So rationing farm power supply and charging a break-even flat tariff made sense. But the play of political gamesmanship transformed this sensible second-best scheme into a 'degenerate system' which incentivized unfettered over-exploitation of groundwater but at the same time made public sector electricity companies bankrupt. In this sense, one can argue that the over-exploitation of groundwater in many parts of India remains state-sanctioned. Henry Vaux's contention that 'groundwater overdraft is self-terminating' would be true in about 20 percent of India's land mass but for the farm power subsidy. Indeed, irrigated agrarian economies in some 100 of India's 650 districts would nearly close down overnight—and groundwater overdraft brought to a halt--if power subsidies were abolished! No politician would accept such a consequence.

5.1 Groundwater Demand Management**:** On demand-side groundwater management, then, the Indian track record is rather indifferent. The standard bureaucratic response has been to make laws with provisions to regulate new tubewells and the pumping of groundwater. But their enforcement has been abysmal; the sheer numbers of small-scale groundwater users makes even their identification a major logistical exercise, leave alone their constant monitoring and regulation. Limited administrative and enforcement capacity is an issue; but even more important has been the reluctance of the government machinery, and actually its sympathy for farmers. Central Groundwater Board categorizes areas (blocks of around 100 villages) according to the state of their groundwater development from white (under-developed) to dark, critical and over-exploited blocks where known groundwater resource has been fully or over-developed. In theory, new tubewells are banned in the latter areas; yet, come an election, and politicians relax the ban. Most collateral damage associated with groundwater over-development—declining low flows, drying up of wet lands, increasing energy costs, mobilization of harmful salts such as fluoride, etc—are evident on large and growing tracts of India.

NGOs have tried some interesting experiments at demand management. The most notable and widely publicized is Andhra Pradesh Farmer Management of Groundwater Program implemented over a dozen years with support from FAO. A recent World Bank report has held out the project as an exemplar in need of outscaling and replication. Basically, the project involved farmer communities in a program of groundwater education and monitoring using simple devices and methodologies. Groundwater data are publicly displayed in real time on Village Panchayat notice boards and farmers are engaged in discussion on how best to arrange their cropping pattern decisions based on available groundwater. The project managers claim enhanced groundwater-literacy and more enlightened decision making, resulting in reduction in groundwater withdrawals in some 700 villages. The project has now run out of funding support and it is a moot question how long will the activities sustain on their own.

Governments in India are often more concerned about the damage the groundwater economy is doing to the electricity industry than to the resource and the environment. Like in Texas, when it comes to groundwater production, distribution and its externalities, the implicit assumption is ‘let the locals figure it among themselves’. But some states have begun to act to cut the damaging power sector impacts of the groundwater economy. West Bengal’s communist government has always championed the cause of farmers but has adopted the classical free-market approach to farm power pricing and supply. It has installed tamper-proof meters on all electrified tubewells, introduced remote meter readers, imposed a time-of-the-day power tariff, cut farm power subsidies. It could do this for two reasons: it already charged very high flat power tariff that put tubewell owners at the mercy of their water buyers; second, less than 100,000 of its nearly 1 million shallow tubewells are electrified. The capacity of electric tubewell owners to put up political opposition is therefore limited. Early assessments show that this change has transformed West Bengal’s groundwater markets from buyers’ into sellers’ markets. Tubewell owners are emerging as ‘water lords’; their clients, marginal farmers dependent on buying water from them, can no longer afford the price and instead lease their land to tubewell owners and become share croppers instead (Mukherji et al. 2010).

While West Bengal has followed the ‘best’ solution to the energy-irrigation conundrum, Gujarat has chosen a ‘second best’ path based on IWMI research recommendations. IWMI researchers pointed out that following the West Bengal solution in Gujarat would impose huge political costs because: [a] 800,000 out of Gujarat’s 1.1 million irrigation tubewells are electrified; [b] most of these are pumping groundwater from depth at which diesel pump would be unviable; and [c] Gujarat’s groundwater irrigators organize quickly and easily around power supply and pricing issues. IWMI therefore suggested that groundwater draft as well as power subsidies can be curtailed by ‘intelligent rationing’ of farm power supply. It argued that tubewell owners do not need 24*7 power supply; they would be happy if plenty of quality power was provided to them at times of peak irrigation need. This was not happening. The electricity company was rationing farm power by providing 3 phase power for 8-12 hours and one or 2 phase power for the remainder of the day. The assumption was that since irrigation pumps need 3 phase power to work, their operation would be restricted to hours of 3-phase power. There were many problems with this arrangement, but two were critical. First, the power ration was imposed on non-farm users of heavy-duty equipment including cottage industry, hospitals, schools, and such other. Second, farmers used capacitors to run their pumps on 2 phase power, there by reducing the voltage for all downstream users. Thus, while the tubewell irrigators held to ransom the entire rural economy, the electricity company managers, frustrated with farm-consumers, treated them with poor quality power supply with low voltage and frequent trips. Everyone was unhappy in this arrangement.

In 2003, Gujarat initiated *Jyotigram* (Lighted Village) scheme under which it invested US $ 250 million to rewire the countryside such that all tubewells were separated from feeders supplying power to non-farm users. With this, it became possible for the electricity company to impose an effective ration on farm power supply on all tubewell irrigators of Gujarat. A 2008 study showed that this helped to reduce farm power subsidies and groundwater withdrawal significantly (Shah et al 2008). More importantly, it created a 'switch-on-off' groundwater economy in which the government had effective lever to control aggregate groundwater use. This worked both ways: in 2009 when the monsoon was delayed and farmers were getting edgy about completing sowing operations, the government persuaded industries to take a power cut to enhance farmers power ration. Contrari-wise, during good monsoons, when farmers' irrigation needs are minimal, the electricity company is able to reduce farm power ration and groundwater draft. Gujarat's solution, though 'second best' seems to have resolved major issues reasonably well. The 2008 study referred to earlier found that farmers were generally happy despite strict ration because, following IWMI recommendations, the electricity company now offered them full voltage power with minimal interruption along a schedule that was strictly adhered to.

5.2 Supply Side Groundwater Management: Indian farmers, NGOs and governments have been far more enthusiastic to augmenting the supply of groundwater resources rather than containing its demand and overdraft. This is understandable for several reasons: first, Indian agriculture has come to rely mostly on dynamic, shallow-circulating groundwater unlike agriculture in say the Middle-Eastern countries like Saudi Arabia where the bulk of the groundwater withdrawn by farmers is fossil groundwater. Second, India's high labor availability increases the feasibility of farm and community level rainwater harvesting and management options that would be unattractive to farmers in a country like Australia. Third, the annual groundwater draft in India is just around 5 percent of the country's rainfall while the natural recharge is 7-10 percent; if farmers can help nature improve its natural groundwater recharge performance, they can make a huge difference to the groundwater balance. Of course, these gross numbers conceal wide regional variations; parts of India in the west and south that get less rainfall withdraw far more groundwater than eastern parts that get most of the rainfall and use little groundwater. Yet, even dry areas of the country get every once in a while massive rainfall events that provide opportunity to recover a part of the accumulated groundwater deficit. Finally, and most importantly, nearly 2/3rd of India is underlain by hard rock formations which have little storage and low transmissivity. Hydro-geologists consider these poor in potential; but farmer communities that try harvesting rainwater and recharge aquifers in many hard rock areas find visible change in water levels in their wells and are able to augment their groundwater supply in times of need. These do not happen in rich alluvial aquifer areas which have massive aquifer storage (as in Punjab, Haryana, western Rajasthan and North Gujarat). Community level groundwater recharge efforts have no visible impacts; and high transmissivity ensures that communities that recharge are able to retrieve very little of the water they put into their aquifers.

This has created a strange paradox in India's groundwater scene. Large pockets of arid alluvial aquifer areas—Punjab, western Uttar Pradesh, Haryana, western Rajasthan and North Gujarat have excellent aquifers with large storage; yet these are the areas where farming communities depend on 'competitive deepening' of their wells to chase declining groundwater levels. In many hard rock areas with intensive groundwater development for irrigation, farming communities have, over the past 4 decades, moved from unfettered private exploitation of groundwater to recognizing the shared nature of the aquifer space and thence to groundwater adaptive management of water resources at local watershed level as outlined in figure 3. 40 years ago, there was hardly any interest in groundwater recharge among farming communities that exploited the resource at will; today, however, harvesting rainfall and using proximate water bodies—including tanks, streams and canals—for groundwater recharge is becoming increasingly common. In southern India, where irrigation tanks were the mainstay of agriculture for millennia, it is now common for tank communities to seal the sluice gate and convert the irrigation tank into a recharge tank. This is also happening with government canals which farmers find more useful for recharge than for direct irrigation. Indian government runs a nation-wide watershed development program to improve soil moisture regime and make rainfed farming productive; however, farmers everywhere judge their efficacy by how much do watershed treatment increase water levels in their wells.

By far the best results of farm power rationing combined with community-based groundwater recharge program on sustainability of groundwater irrigation can be witnessed in Gujarat. Here, a mass-movement for groundwater recharge was catalyzed by religious Guru's and spiritual leader after a debilitating drought in 1986-8 in Saurashtra and Kutch, two of India's driest regions. Early successes fueled popular enthusiasm; voluntary labor was mobilized on a massive scale to modify open wells for recharge, construct check dams and percolation ponds in thousands. Cement factories offered free cement; and diamond merchants hailing from the area threw in cash contribution. Soon, political leaders spotted a great opportunity to earn brawny points; and offered support to farmer communities to build community-scale recharge structures in massive numbers. The scheme performed best in Saurashtra and Kachchh regions; but for the state as a whole, by December 2008, nearly 500,000 recharge structures were created—113738 check dams, 55917 bori bandhs (sand-bag dams), 240199 farm ponds, besides 62532 large and small check dams constructed under the oversight of the Water Resources Department of the Government of Gujarat[3]—all in a campaign mode.

There is a controversy raging among hydro-geologists about whether this run-away rainwater harvesting is creating much new water and value mostly because the Saurashtra and Kutch hardrock aquifers have very limited storage. However, farmers in these drought-prone region swear by check-dams; and over 20 years after the movement began, constructing new check dams has still not gone out of fashion. Other evidence suggest these are helping. Since 2000, when Government of India announced a target of 4% annual growth in agriculture while national achievement has barely crossed 2%/year, Gujarat has posted agricultural growth rate of a miraculous 9.6% during 2000-2008 (Shah et al 2009). This was made possible, among other things, by a 30% increase in groundwater irrigated area. Despite this increased groundwater use in agriculture, Gujarat seems to be the only state in India where the groundwater regime is improving as shown in figure 3. In 2000, large areas were experiencing declining groundwater levels during May-December period when they should be rising. But in 2008, areas showing decline were much smaller. A succession of good monsoons helped; but what thousands of community level recharge structures seem to do is to enhance the drought-resilience that a good rainfall season imparts to the agricultural economy of a region.

6. SUMMARY AND CONCLUSIONS:

This paper did three things: first, we outlined the shape and structure of the global groundwater irrigation economy; second, we explored the range of groundwater instruments that have been

[3] http://guj-nwrws.gujarat.gov.in/pdf/check_demo_240309.pdf

tried out in different parts of the world with varying degrees of success; third, we specifically examined how India is coping with groundwater over-development issues. We noted that many approaches tries in the industrialized world have a great appeal to policy makers in India. However, the structure of India's groundwater economy—with millions of small-scale groundwater users—makes the implementation of such approaches problematic. India's groundwater economy and its management challenges are huge and urgent; and India needs robust approaches that can work in large areas and on large numbers of people in quick time. Contrasting approaches to the co-management of groundwater resource and farm power supply tried out in Gujarat and West Bengal offers a robust, quick acting demand-management tool that has appeal in all regions where the groundwater economy depends on energy subsidies. In West Bengal, electricity price is used as the key tool for groundwater demand management. In Gujarat, quantity restrictions on farm power supply are the key groundwater demand management tool.

The Gujarat approach would work where groundwater over-draft is sustained by energy subsidies. In the America's, Mexico is one country where the Gujarat approach to energy-irrigation nexus may have relevance. Groundwater irrigators in Mexico enjoy a significant power subsidy of around US $ 1600/ha/year. It can be argued that farmers can not have subsidized farm power supply in unlimited quantity; and a case can be made to raise power price to farmers or impose a ration on subsidized power supply—both of which will encourage water use efficiency and curtain groundwater draft.

The Indian NGO effort to organize farmer communities for local management of groundwater in Andhra Pradesh has closely followed the Mexican experiment with Aquifer Management

Committees (COTAs). In my assessment, both have merit and produced laudable outcomes by educating farmers on groundwater processes and creating an information base on aquifer characteristics. However, they have common limitations: first, COTAs of Mexico are unlikely to sustain without constant support from CAN; likewise, the sustainability of the Andhra Pradesh Farmer Management of Groundwater Project too is open to question now that FAO support has ended. In their regulatory effectiveness, both are slow in producing large-scale results. Finally, it is really doubtful whether on their own, small farmers of India would agree to reduce groundwater use to save it for future generation. When I asked a north Gujarat farmer why he is not saving water for future generation, he quipped, "so that *my* future generation will not need to be farmers".

India, at least hard rock India will likely take to ground-water centric adaptive management of rain water and surface water bodies in response to progressive intensification of groundwater irrigation. In tank commands and even command areas of major public canal systems, groundwater wells are fast becoming prime source of irrigation water. This is because India's small farmers are intensifying their land use by taking 2 or 3 crops a year which wells can support but surface sources can not. As a result, new tanks/check dams are being dug and existing ones getting modified to enhance recharge. Many public irrigation systems too generate more value by keeping the aquifers recharged than by directly irrigating crops. All in all, the groundwater boom is rewriting India's irrigation and water management rule book.

India's groundwater situation is in many ways unique and different from what obtains in the middle-east or in the Western and Southern US and Mexico; equally unique, therefore, are the responses that India is evolving. Attempts towards copycat transplantation of groundwater management lessons from industrialized world— tradable property rights, water pricing, etc-- have come unstuck. By the same token, rationing power supply to reduce groundwater draft may be hardly acceptable to California farmers, neither are Texas farmers likely to be enthusiastic about large-scale transformation of the geo-morphology of their landscape to enhance infiltration of rainwater into their aquifers. The upshot of the discussion is that groundwater governance has more to do with people, social structure and the nature of the state than with groundwater; and to be effective, groundwater governance strategies are best tailed to fit the socio-ecological specifics of a locale than blindly transplanted from totally different contexts.

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Figure 1. Growth in groundwater use in selected countries (author's estimate)

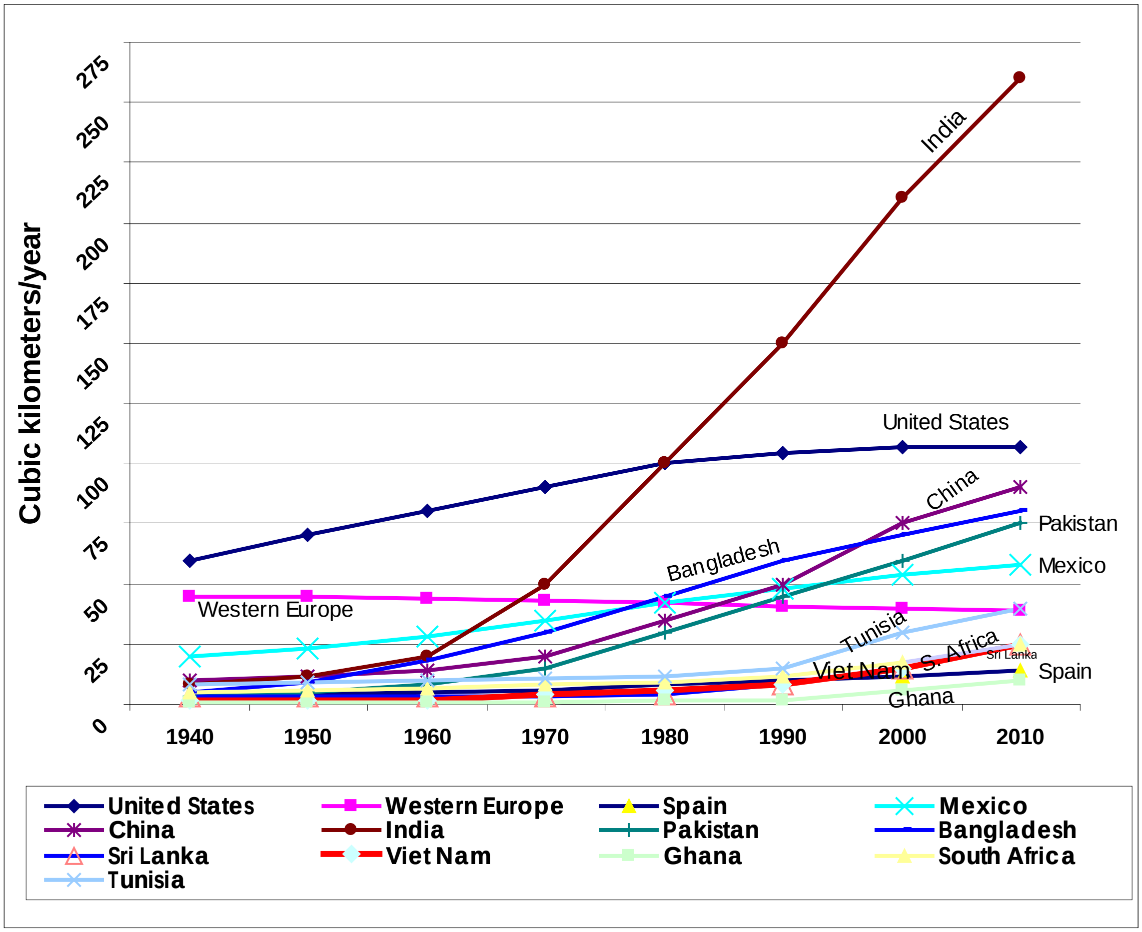

Figure 2a : Electricity Network Before JGS

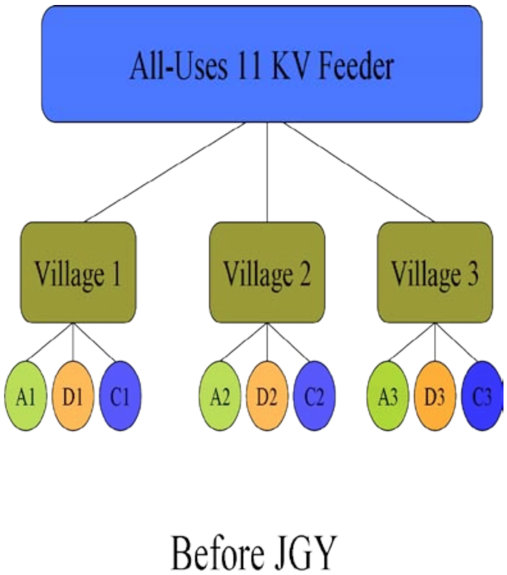

Figure 2b: Electricity Network after JGS

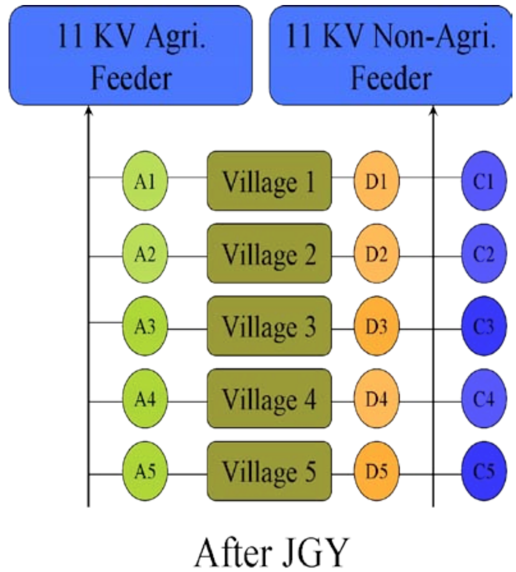

Figure 3 Monsoonal Changes in Groundwater levels in 2000 and 2008

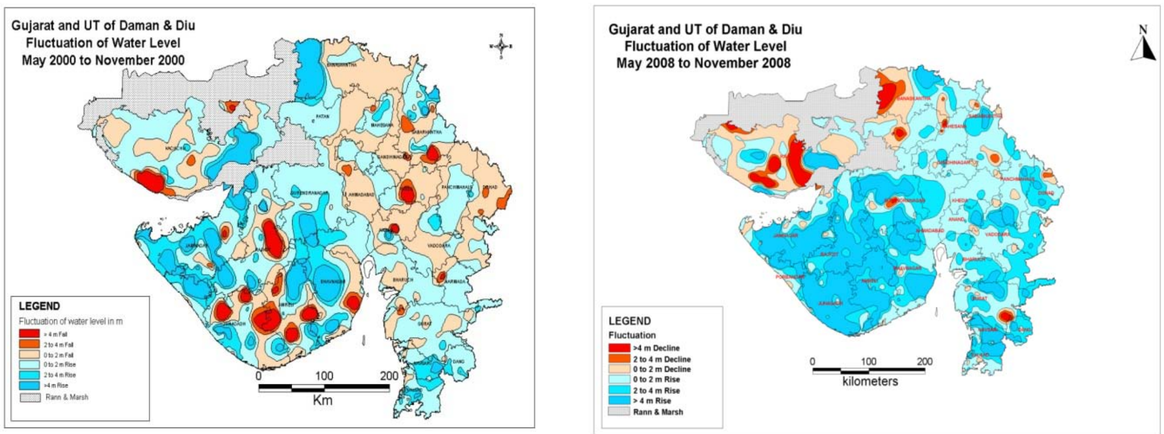

Table 1: Part of total area equipped for irrigation by groundwater

	Continent Regions	Sub regions	Area equipped for irrigation		
			Total	Groundwater	Gw as % of total (% of the word groundwater irrigated area)
			(1 000ha)	(1 000 ha)	(%)
	World		**302,959**	**113,094**	**37.3** **(100%)**
1	**Africa**		**13,576**	**2,506**	**18.5** **(2.3%)**
2	**Americas**		**50,967**	**21,706**	**42.6** **(19.3%)**
3	**Asia**	**211,796**	**80,582**	**38.0** **(70.8%)**	
4	**Europe**	**22,652**	**7,350**	**32.4** **(6.6%)**	
5	**Oceania**	**3,967**	**950**	**23.9** **(0.8%)**	37.8

(Source: Siebert et al , 2010)

Table 2 Global typology of groundwater use in agriculture and animal husbandry

System	*Arid agrarianism*	*Industrial agriculture*	*Smallholder intensive farming*	*Extensive pastoralism*
Region	Middle East and North Africa[a]	U.S., Australia, Spain, Italy, Mexico	Monsoon Asia[b]	West and sub-Saharan Africa
Groundwater-irrigated area	<6 million ha	15 million ha	>100 million ha	>500 million ha of grazing land
Climate	Arid	Semiarid	Semiarid to humid; monsoon	Arid to semiarid
Water resources per person	Very small	Good to very good	Moderate to good	Moderate to good
Population pressure on agricultural land	Low to medium	Low to very low	High to very high	Low, with high pressure on grazing areas
Percentage of geographic area under cultivation	1–5%	5–50%	40–60%	5–8%
Percentage of cultivated areas under irrigation	30–90%	2–15%	40–70%	>5%
Percentage of irrigated	40–90%	5–20%	10–60%	<1%

areas under groundwater irrigation				
Percentage of geographic area under groundwater irrigation	0.12–4.0%	0.001–1.5%	1.6–25.0%	<0.001%c
Organization of agriculture	Medium size, market-based	Industrial, export-oriented farming	Smallholder farming and intensive diversification	Small-scale pastoralism, smallholder farming
Driver of groundwater irrigation	Lack of alternative irrigation	Wealth-creating agriculture	Land-augmenting, labor-absorbing agriculture	Stock watering
Groundwater contribution to national economy	Low: <2–3% of GDP	Low: less than 0.5% of GDP	Moderate: 5–20% of GDP	Moderate: 5–20% of GDP
Groundwater contribution to national welfare	Low to moderate	Low to very low	40–50% of rural population, 40–80% of food supply	High for extensive pastoralism, domestic water supply, and smallholder agriculture
Groundwater contribution to poverty reduction	Moderate	Very low	Very high	Central to pastoral livelihoods
Gross output supported by groundwater (US$)	$6–8 billion	$100–120 billion	$ 250–300 billion	$2–3 billion

[a]Iran, Iraq, Libya, Tunisia, Morocco, Turkey, Algeria, Egypt.

[b]India, Pakistan, Nepal, Bangladesh, North China, Afghanistan.

[c]Groundwater-supported grazing areas for stock watering are about 17% of total area (Giordano 2006).

Sources: FAO Global Map of Irrigated Areas

(http://www.fao.org/ag/agl/aglw/aquastat/irrigationmap/index.stm, FAO Aquastat 2003.

Table 3 Organization of groundwater irrigation economies of selected countries, c. 2000

Country	*Annual groundwater use (km^3)*	*Agricultural groundwater structures (million)*	*Average extraction/ structure (m^3/year)*	*Population dependent on groundwater irrigation (percentage)*	*Average annual farm income per farmworker (US$)*
India	210	17.5	12,000	55–60	~350
Pakistan	55	0.9	60,000	60–65	~400
China	105	4.5	23,000	22–25	~458
Iran	29	0.5	58,000	12–18	~2,200
Mexico	29	0.07	414,285	5–6	3,758
United States	100	0.2	500,000	<1–2	67,800

Sources: www.agnet.org/library/stats/2003/24.html.