Groundwater conservation and management in India: Application of IoS and Wade frameworks

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Abstract

While India's farmers boost of their contribution to green revolution supported by groundwater irrigation, being the largest pumpers of groundwater are facing the predicament of negative externalities, inefficiencies and inequities due to massive initial and premature well failure and declining yield of wells. Currently groundwater contributes to 80 percent of India's irrigation. With declining Government investment in agriculture, farmers' investments in agriculture account for 75 percent of the total, a major portion towards irrigation. The modern and extractive deep borewells and submersible pumpsets have gradually displaced the traditional and sustainable water extraction structures. In addition, the irrigation tanks which were performing the dual role of water supply and groundwater recharge are relegated due to institutional failure coupled with the farmers' practice of agriculture technologies neglecting the traditional practices. Inconsistencies among water and land institutions, compartmentalization of water resource, multiplicity of organizations dealing with water, lack of water and irrigation literacy, subdivision and fragmentation of land and water resources, perverse subsidies, lack of well defined property rights, market forces, have exacerbated the predicament. This paper provides institutional, technological, outreach and market solutions to address the predicament using the IoS and Wade frameworks. Imposing a cap on the number of functioning irrigation wells, promotion of low water use crops and technologies including micro irrigation, provision of water flow meters to enable farmers for efficient water and crop budgeting, an effective irrigation management service, massive awareness programs regarding irrigation and water literacy with emphasis on educating farm women as also incorporating in school syllabi, linking developmental programs with adoption of water efficient devices, and methods are among the vital solutions suggested to address the predicament, before attempting institutional reforms in groundwater regulation.

Key words: Groundwater, Externality, IoS, Institution, climate change, Andhra Pradesh

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INTRODUCTION

Water is the elixir of life supporting agriculture, domestic, industrial needs. Irrigation has been shaping the lives and societies of people in the tropics. In India more than 90 percent of water is used for irrigation. Irrigation uses both surface water and groundwater. Surface water is provided by public investment on tanks, dams and reservoirs, while groundwater has to be extracted and used by farmer's private investment on irrigation well/s. According to IWMI "…..currently, over 80% of irrigated agriculture in India is supported by groundwater, resulting in severe overexploitation of this resource[2]. The number of irrigation pumpsets in India increased from 0.15 million in 1950s to around 19 million by 2000 and is annually pumping 220 to 230 billion cubic meters, twice that of the USA and six times that of Western Europe, ascending as the world's largest extractor of groundwater (Fig 1).

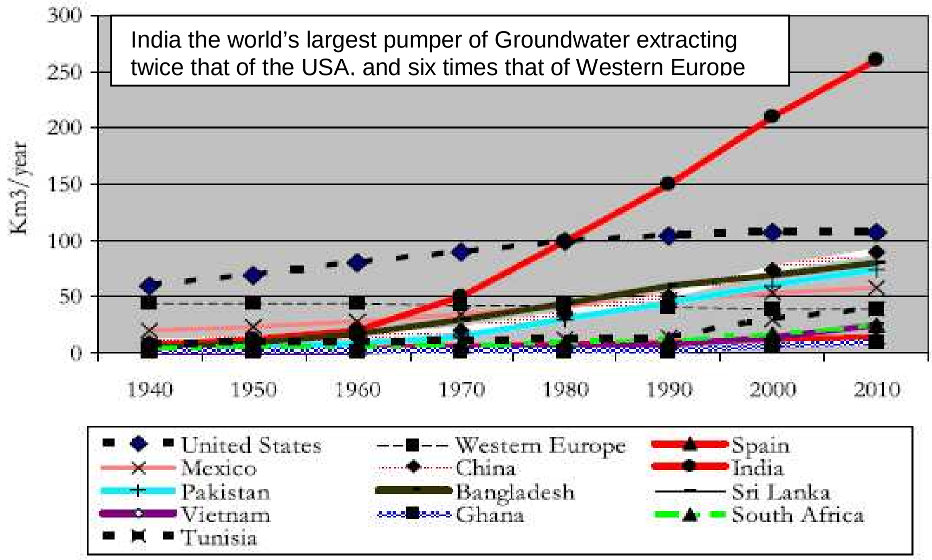


Fig 1: Groundwater pump volume by different countries
Source: Tushaar Shah (2009) http://iopscience.iop.org/1748-9326/4/3/035005/pdf/1748-9326_4_3_035005.pdf

In Hyderabad megacity area, about 93 percent of area is irrigated by groundwater wells. In addition, water use in irrigation / agriculture is 'consumptive use'[3] that cannot be recovered, while water in all other uses is 'non-consumptive use' and can be recovered. Both surface water and groundwater are complementary and thus water use efficiency is relatively more important in agriculture than other sectors, since savings in water can make it amply available for other productive uses. *Prima facie* indicators of inefficiency in surface water use are relatively low output and low returns per unit

[2] http://southasia.iwmi.org/Data/Sites/15/Documents/PDF/IWMI_South_Asia_Brochure,2005)

[3] Consumptive use is water applied to crops or livestock, that evaporates and not returned to the immediate environment. All water used indoors can be recycled and hence called non-consumptive use. But water used outdoor (say agriculture) cannot be recycled due to evaporation, hence called "consumptive use."

volume of water and per acre of irrigated area, increase in water logged areas, salinity and alkalinity areas. *Prima facie* indicators of groundwater inefficiency are *inter alia* raising costs of groundwater extraction, externalities, increased probabilities of initial and premature well failure, reduced life and age of irrigation wells, reduced groundwater yield of wells, increased depth to groundwater. With this backdrop, this proposal deals with water use efficiency in agriculture as affected by incentives and institutional failures in Hyderabad Megacity region in the wake of climate change.

Problem situation

Due to growing population including migration to urban and peri-urban areas, demand for food, demand for habitat and the overall pressure on water resources is mounting. The vagaries of weather including climate change add to the predicament. This paper highlights the predicament in the megacity Hyderabad in Andhra Pradesh (AP) and the possible solutions using the IoS (Hagedorn, 2008) and Wade (1988) frameworks. The pressure on water resources has reached unsustainable limits threatening efficiency and equity. This phenomenon will continue unabated due to shift in crop patterns towards water intensive food, cash crops and livestock.

In megacity Hyderabad, 93 percent of water used in irrigation is contributed by groundwater. In AP this proportion is 53 percent (Devender reddy and Vijaya kumari, 2007). With very little control on groundwater extraction, groundwater depletion is imminent and though the process is reversible, the time taken is so long that unless sustainably used, it is as good as irreversibility. Urban groundwater use is under pressure to cope with the demand from growing urban population and increased percapita water use in the fastest growing cities like Hyderabad, Bangalore, Coimbatore, pune all located in hard rock areas.

GROUNDWATER AND CLIMATE CHANGE

With the advent of shallow and deep tubewell technologies, dug wells where manual lifts were being used, are no longer common in AP and the megacity of Hyderabad. Groundwater has to be pumped from depths beyond 500 feet in peninsular India using (largely thermal) energy. With 20 million irrigation wells (pumpsets) in operation in India, the use of electricity and diesel is responsible for 16–25 million tonnes of carbon emissions forming 4–6% of India’s total carbon emission. Thus the groundwater hotspots are western and peninsular India, which are crucial for both climate change mitigation and adaptation (Tushaar Shah, 2009).

UNRESOLVED ISSUES

Groundwater resource is akin to the story of the ‘six blind men and an elephant’! Due to invisible and complex nature of management of the resource, the extraction as well as recharge in hard rock areas (HRAs) characterized by low rainfall, high temperatures, low recharge, absence of perennial river flow, the property rights to groundwater are nebulous. Thus, the relationship among factors impinging on groundwater recharge (supply side factors) and discharge (demand side factors) is rigmarole.

In HRAs, the occurrence of groundwater is highly sensitive to interactive effects of wells and renders groundwater as a fugitive resource. Wantrup (1952) opines that 'definite property rights (to groundwater) belong only to those who are in possession - that is who gets there fastest with the mostest'. Thus, the sustainability of groundwater institutions depends *inter alia* upon the nature of aquifer, volume of groundwater recharge and discharge, isolation distance between wells, recharge efforts, rainfall, age of irrigation well, crop pattern, number of pumpers, all influencing stock and flow of groundwater.

Is Groundwater an open access resource?

The nature of property rights of groundwater is determined by supply and demand of/for groundwater use (Chandrakanth and Arun, 1997). Early comer farmers in groundwater irrigation feeling that s/he is enjoying (permanent) private property rights to groundwater, will suddenly be shattered once there emerge a set of neighboring farmers who tap groundwater from deeper layers from borewells causing well failure due to cumulative well interference.

In India, the rights in groundwater belong to the land owner as groundwater is attached to the land property and Hyderabad megacity is no exception (Indian Easements Act 1882)[4]. Hence, only landowners can own groundwater (Chatrapati Singh (1992). Thus, groundwater cannot be an open access resource. Next, even though land owners own groundwater de jure, this private property right is limited by the huge volume of investment necessary in drilling irrigation well(s) and high well failure probability, which makes a few among them to have both physical and financial access to groundwater for some time period as the access is conditioned by cumulative interference among wells.

Even considering the fact that the price of electricity to pump groundwater is fully subsidized (as it exists / existed in India), unless the farmer has physical access to groundwater, even if electricity is available, s/he has no access since, initial and premature failures are becoming rampant.

In the eastern dry zone of Karnataka, in peninsular India, the probability of well failure is estimated to be 40 percent (Nagaraj, Chandakanth and Gurumurthy, 1994) which implies that a farmer has to drill at least two wells, one of which may be successful. Thus, wells can exist without groundwater ! And it is difficult to admit that ‘groundwater is an open access resource’ at the one extreme or that ‘groundwater has private property rights’ at the other extreme.

[4] http://www.commonlii.org/in/legis/num_act/iea1882158/

Is groundwater a common property resource?

In the HRAs, drilling irrigation wells is increasing at a compound growth rate of ten percent[5]. Here, if the groundwater extraction is below 65 percent of recharge, the region is called as ‘white’, if the recharge is between 65 and 85 percent, the region is classified as ‘grey’ and if it is above 85 percent, the region is characterized as ‘dark’ and above 100 percent is red. This classification has further undergone change from ‘region’ to ‘watershed’ level. The density of wells per unit area as well as the number of wells per million cubic meter of groundwater which determine the degree of interactive effects of wells are both increasing over time in HRAs.

Under these circumstances the groundwater rights are obscure since farmers are not realizing the fact that each one's extraction is a function of the neighboring wells’ extraction at a time and over time facing reciprocal externality (Dasgupta, 1982). In addition, aquifer boundaries are difficult to be demarcated. In HRAs, over time, the cumulative interference of wells is increasing and this has led to reduction in life/age of the wells, increasing initial and premature failure as well as reduction in the gross area irrigated by wells (Thamanadevi, 2008). In these circumstances it is also difficult to assign common property rights de jure or de facto to groundwater[6].

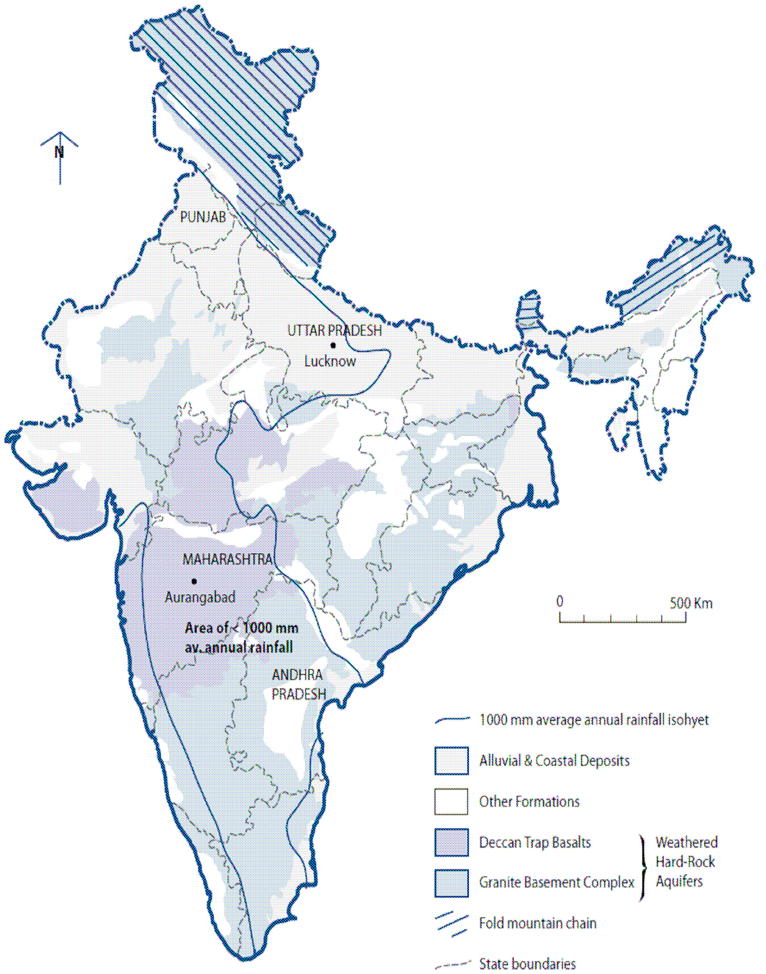
Hence, in HRAs (Fig 2), property rights to groundwater are nebulous. Therefore groundwater literacy, conservation, wise use and management are crucial and collective action is logically the only institution which can help to achieve sustainable groundwater management at low transaction cost.

Lack of well defined models for community based groundwater management also results in water use inefficiency, and the governments have also not attempted community based institutions for groundwater management. As groundwater and surface water are closely linked, planning and management of groundwater and surface water should go together as in river basin approach even focusing on conjunctive use.

Fig 2: India’s hydro geological formations of HRAs

[5] http://ageconsearch.umn.edu/bitstream/54186/1/UAS_MSc_Ag_Econ_Thesis_by_Thamanadevi_2008[1].pdf

[6]. Several studies presented at the workshop on "Water management: India's groundwater challenge" at VIKSAT, Ahmadabad in December 1993 have attributed 'common property rights' to groundwater resource. See Marcus Moench (Ed), Groundwater management: The supply dominated focus of traditional, NGO and Government efforts, VIKSAT, Thaltej Tekra, Ahmadabad, 1995.



Source: World Bank, 2010, Deep Wells and Prudence:Towards Pragmatic Action for Addressing Groundwater Overexploitation in India, Report 51676

The groundwater resource status, socio economic status, socio economic drivers for groundwater demand (Table 1) indicate that high water crops like paddy, wheat and sugarcane which occupy 28 percent of gross area, are cultivated on (or consume) 48 percent of groundwater irrigation (area)

Table 1: Socio economic drivers of groundwater demand

	Groundwater resource status					Socioeconomic status		Socioeconomic drivers for groundwater demand and pollution								
								Drinking water	Irrigated agriculture						Industries	
State	In-storage groundwater resource (cubic kilometers) (alluvium, hard rocks)	Net annual groundwater availability (cubic kilometers)	Annual use (cubic kilometers)	Groundwater development (%)	Critical and overexploited units (%)	Per capita income as percent of all India average	Poverty index (% of population)	Population density as percent of all India average	Gross irrigated area (million hectares)	Marginal to medium landholdings (% of landholdings < 10 hectares)	Large landholdings (% of landholdings > 10 hectares)	High-water-demanding (rice, wheat, sugar cane) (% of gross area)	Irrigated with groundwater (% of gross area)	Power consumption (gigawatt hours/cubic kilometer)	High-water-demanding industries	Number of wells (million), as at March 2006
Andhra Pradesh	10	33	15	45	24	92	16	84	5	92	8	66	39	1,131	Low	1.92
Gujarat	10	15	12	76	19	114	17	83	4	89	11	29	63	1,160	High	0.78
Haryana	42	9	10	109	66	129	14	146	5	77	23	65	29	696	High	0.47
Karnataka	2	15	11	70	68	84	25	84	3	89	11	37	34	1,024	High	1.36
Kerala	1	6	3	47	13	114	15	82	0.4	93	7	40	28	128	Low	0.44
Madhya Pradesh	4	35	17	48	9	54	38	60	6	84	16	86	64	388	Low	2.77
Maharashtra	4	31	15	48	2	125	31	96	4	93	7	36	50	804	High	2.45
Punjab	91	21	31	145	79	124	8	147	8	73	27	79	40	276	Low	0.75
Rajasthan	13	10	13	125	80	66	22	50	7	60	40	33	60	520	Low	0.63
Tamil Nadu	10	21	18	85	46	105	23	146	2	93	7	56	52	610	High	1.66
Uttar Pradesh	350	70	49	70	7	46	33	102	18	97	3	82	52	513	High	2.61
All India	**1,081**	**399**	**230**	**58**	**19**	**100**	**28**	**100**	**55**	**87**	**13**	**28**	**48**	**524**		**19.59**

<u>Source:</u> World Bank, 2010, Deep Wells and Prudence:Towards Pragmatic Action for Addressing Groundwater Overexploitation in India, Report 51676

ISSUES

In the process of mitigation of effects of climate change, the role of water institutions which *inter alia* structure incentives and penalties is crucial in bringing about water use efficiency and equity. It is well known that for public goods, institutions and/or markets singularly will not be able to effectively manage. As the water resource is indispensable and is subject to the peculiar attributes of public good, this proposal deals with analyzing the existing institutions, and developing policies / institutions to mitigate effects of climate change on water use through institutional innovations as well as improving energy efficiency for urban and sub urban Hyderabad. An example clearly illustrates how water use efficiency and mitigation of climate change can mince. Some farmers in Megacity Hyderabad region extract groundwater to cultivate rice. Rice uses around 40 acre inches of groundwater per acre and releases substantial methane. If markets and institutions facilitate cultivation of SRI and Aerobic rice, this results in savings in precious groundwater and helps to achieve the dual goal of climate change and sustainable use of groundwater. Thus, water use efficiency and climate change mitigation go along with each other.

Both surface water and groundwater in Hyderabad are dependent on the monsoonal rains. More than 93 percent of groundwater is used for irrigation. The rainfed, surface water irrigated and groundwater irrigated agriculture all suffer from the vagaries of monsoon. Thus, the quantum and distribution of rainfall is a major determinant of the farm economy irrespective of whether the farm is rain fed or irrigated. Thus, irrigation efficiency in general and economic efficiency in the use of irrigation water in particular shapes the economy of the farming sector.

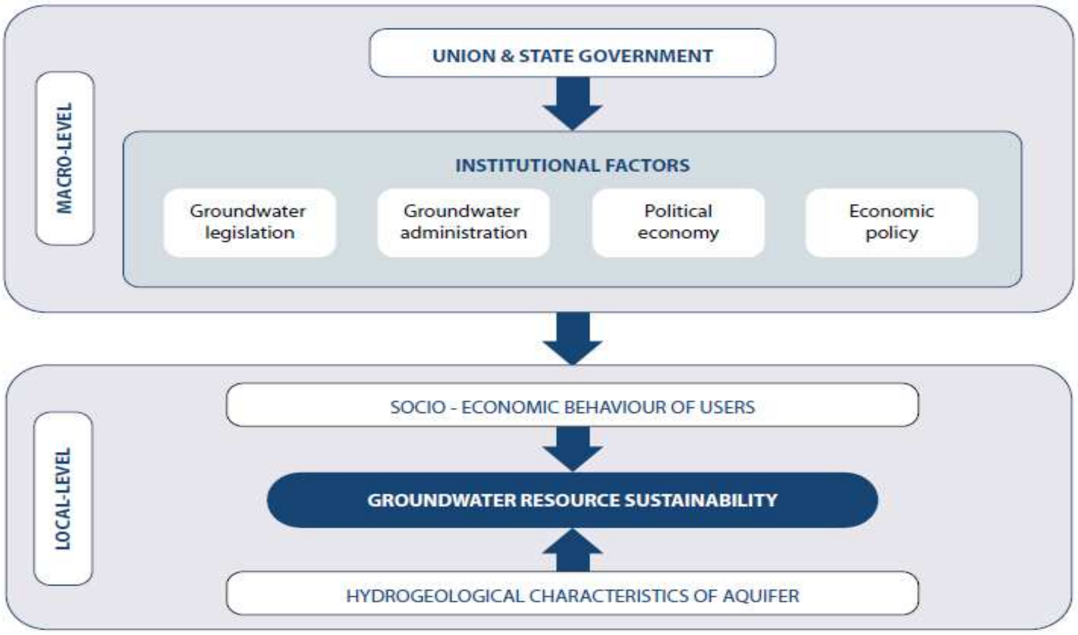
In the surface water irrigation dominated by reservoirs and canal systems, the entire investment is borne by the public, while farmer does not bear any cost of water except for flat water charge. In several states, farmers do not remit the water cess, virtually treating surface water as ‘free’ . In the case of groundwater irrigation however, the farmer necessarily contributes for drilling / constructing well, pump set, electrical fixtures, conveyance pipes, and other accessories, including drip / sprinkler irrigation if any, which all constitute around 75-80 percent of the cost of groundwater. In addition, making them to pay for electricity to pump groundwater may put them at a disadvantage when compared with surface irrigation farmers. With the increasing number of irrigation bore wells, a significant turn from the traditional dug wells all over the State, the dynamics of initial and later failures of irrigation wells places farmers in a state of predicament from which they find it extremely difficult to be resilient.

Significance

Water use efficiency involves use of both market and institutional approaches along with technology adoption. Their right combination with the right governance structure enables the scarce resource to be sustainably managed and used. As water is indispensable, sustainable use is crucial and vital. Institutions of Sustainability framework[7] clearly demonstrates its application to address sustainable use of such an indispensable natural and environmental resource. Next to land, water has maximum organizations for monitoring, but the success is little. Governments and policy makers are devoting increasing budgets on surface water resources, neglecting groundwater resources though the society and public are largely dependent on groundwater than surface water for both irrigation and drinking water needs. Groundwater resource conservation and management has continued to receive low budgetary as well as institutional support. In groundwater management, it is crucial for the users to manage themselves, the hydro geological, socio-economic and institutional factors influence groundwater at micro and macro levels (Fig 3)

[7] K. Hagedorn http://www.agrar.hu-berlin.de/struktur-en/institute-en/wisola-en/fg-en/ress-en/forschungskonzep-en/IoS-en

Fig 3: Factors influencing groundwater resource sustainability



Source: World Bank, 2010, Deep Wells and Prudence:Towards Pragmatic Action for Addressing Groundwater Overexploitation in India, Report 51676

Research questions

Since 93 percent of area in Hyderabad megacity is irrigated by groundwater, surface water is largely used for domestic and industrial use. This study thus concentrates on groundwater use efficiency as influenced by institutions and incentives in the ambit of climate change. Considering the dynamics of groundwater irrigation in AP (Table 2) between 1980 and 2004, dug wells dominated in 1980s, the power consumption was around 800 kilo watt hours irrespective of the numeraire. By 2004, the power consumption was around 5000 to 7000 kilo watt hours. Thus, with the gradual failure of dug wells and with the advent of borewell technology, in 24 years (between 1980 and 2004), the area irrigated per well increased by 50 percent while the power consumption per well increased by 710 percent (Table 2). Thus, while area irrigated per well increased by around 2 percent per year, the power consumption per well increased by 30 percent per year. This can happen if there has been a drastic shift in crop pattern, promoting water intensive crops in AP and/or the groundwater being extracted from deeper layers using higher electricity, and/or use of low quality irrigation pumpsets and/or low yielding wells and/or groundwater markets and/or climate change factors and/or errors in estimation of electricity use in groundwater irrigation, since the number of wells has increased only by 64 percent over 24 years.

Table 2: Power consumption per IP set and per ha of land over time in AP

Particulars of wells and energy use in AP	YEAR		
	1980	1998	2004
Number of irrigation water wells (million)	1.06	1.40	1.74
Area under irrigation with groundwater (million ha)	1.12	1.76	2.48
Power consumption for pumping (Gigawatt-hours)	920	10220	12240
Power consumption Per irrigation well in KWHs	868	7300	7034
Power consumption per ha of irrigated land in KWHs	821	5807	4935
Area irrigated per irrigation well	0.95	1.26	1.43

Source: Adopted from World Bank, 2010, Deep Wells and Prudence:Towards Pragmatic Action for Addressing Groundwater Overexploitation in India, Report 51676

Several primary data based studies indicate the increase in (real) cost of groundwater irrigation, increase in negative externalities due to cumulative interference among irrigation wells, increasing proportion of well failures and the subsequent losses in investment (Chandrakanth, Bisrat and Bhat, 2004). For AP, while similar studies were not available, the macro indicators of the micro level negative externalities were available in the form of investment lost due to well failure (Table 3), where the percentage of investment lost due to borewell failure is a colossal 56 percent. This is also reflective of a similar probability of well failure and has efficiency and equity implications on marginal and small farmers who are unable to cope with such a magnitude of well failure and the subsequent losses in investment. The investment lost in Hyderabad megacity region is more than 50 percent with equity implications on marginal and small farmers including large farmers.

Table 3: Percentage of Investment lost due to failure of Borewells in Andhra Pradesh

Region	Marginal	Small	Medium	Large	All
North coastal Andra	25.0	-	15.0	56.8	30.4
South coastal Andhra	58.0	49.8	49.1	34.2	45.9
Rayalaseema	61.9	47.8	54.4	59.6	54.9
South Telangana	59.8	74.3	63.0	67.4	66.5

North Telangana	32.9	46.1	52.5	59.1	51.6
All Sample Districts	55.9	53.2	55.9	58.5	56.1

Source:
http://www.aponline.gov.in/Apportal/HumanDevelopmentReport2007/APHDR_2007_Chapter6.pdf

Groundwater pumping and climate change

Even though climate change and groundwater discussions are at an early stage in India, it has been predicted that climate change will increase the demand for groundwater for agriculture and other uses. Further, studies have demonstrated the scope for reducing Carbon footprint of groundwater. For every meter decline in pumping water levels, GHG emissions increase by 6 percent in AP. For one percent increase in groundwater irrigated area, there is a 2.2 percent increase in GHG. Due to CGR of 3 percent in groundwater irrigated area per year, the GHG emission is increasing at 6.6 percent. For 1% increase in the share of diesel pumps to total pumps, the GHG emissions reduce by 0.3 percent. For 1 percent increase in irrigation efficiency, the GHG emissions reduce by 2.1 percent (Tushaar Shah, 2009). Thus, in the context of climate change, drip irrigation and use of biodiesel are crucial due to win-win-win situation as it saves groundwater use, releases less CO2 while pumping groundwater, and augments area irrigated. However increasing reliance on groundwater is disadvantageous since hard rock aquifers which form 65 percent of India's area are slow to recharge and have limited storage and groundwater pumping is energy intensive and increases carbon foot print.

The crucial research questions are:

1. What is the response of decline in pumping groundwater level, increase in groundwater irrigated area, increase in irrigation efficiency, use of biodiesel to pump groundwater and increase in area under drip irrigation with respect to GHG emissions?
2. what is the economic and equity implications of increasing probability of initial and premature well failure
3. What are the reasons for a lower (2) percent increase in area irrigated per well but a higher (30) percent increase in the electricity consumption per well per year
4. what is the role of social capital in groundwater use efficiency

EXISTING LITERATURE

In order to pump groundwater, farmers in India (and AP) use electrical energy and diesel. Thus, whether energy and economic growth are closely linked is a question. Applying the Engle–Granger cointegration approach and the Granger causality test for 1950–1996 (Shyamal Paul and Bhattacharya, 2004), the study indicates that there is bi-directional causality between energy consumption and economic growth.

There are however estimates of electricity use (for AP) per hectare of irrigation which is around 5864 Kilo Watt Hours per year (quoted by Tushaar Shah, 2009). According to the study, power used by irrigation pumpsets forms around 15 percent of the total power generated in India and the irrigation pumpsets operate at only 40 percent efficiency. In another study quoting Central Electrical Authority, Tushaar Shah (2009) indicated that by 1999-2000 itself, India had 20 million irrigation pumpsets and 25 percent of farmers owned irrigation wells. But the Minor Irrigation census of 2000-01 indicates that there are 16.78 million irrigation pumpsets in India. In a study on electricity use, it is indicated that electricity is a major input in agriculture and accounts for more than 50 % of the final energy consumption in agriculture and forms 22% of final electricity consumed in India in 2004 (Shyamal Paul and Bhattacharya, 2004)[8]. And India by March 2008 had 15.4 million pump sets. Thus, each source of information gives different statistics.

Dejure-De facto gaps

Due to issues of political economy gripped with lack of education and awareness, there are several laws and acts governing water resource. However, the compliance to legislation is at stake due to issues of political economy and rent seeking. Thus, India has authority for reformation but has little capacity for implementation. In India, the problem of groundwater overexploitation does not necessarily arise from inadequate legislation and therefore cannot be solved only through legislative remedies[9]. Thus, community management with proper education and awareness creation among members of the community can be an alternative mechanism in hard rock areas.

Supply side factors

In megacity Hyderabad, about 90 percent of groundwater is used for irrigation and is extracted through (private) irrigation well/s. The factors which shape availability (supply) of groundwater are, the number of rainy days, volume of rainfall, the nature of aquifer (confined or unconfined), the proximity to recharge points, the presence of dykes or groundwater barriers and lineaments, the surface water bodies, commitment to recharge efforts, quality and HP of irrigation pumpsets, supply of electricity at regular voltage and others.

Demand side factors

The main factors which influence demand for groundwater are cropping pattern (cultivation of low water intensive food / cash crops versus high water intensive food / cash crops), demand for horticultural produce like fruits and vegetables, proximity of metropolitan centers, irrigation methods (flood irrigation / flow irrigation / furrow irrigation / drip / sprinkler/ micro irrigation systems), subsidized electrical power to lift groundwater; presence of a few number of well owners versus large number of well owners, early comer / late comer in groundwater irrigation, age of irrigation well, degree of well interference, type of well (dug well, borewell), type of groundwater extraction

[8] http://www.escholarship.org/uc/item/0f05n9cr
[9] World Bank, 2010 Report 51676.

devices (manual lifts / power lifts with varying HPs of pumpsets), well density, number of wells per unit of groundwater, Proximity to peri- urban area.

GROUNDWATER OVER-EXTRACTION ATTRIBUTED TO ELECTRICITY SUBSIDY

Electricity use for pumping groundwater is often highlighted as the single strong cause for overexploitation. Field work based studies indicate that the negative externalities faced by the farmers due to cumulative interference of irrigation wells are largely responsible for well failure in the HRAs (Chandrakanth, 2002). And the electricity subsidy farmers receive is only the tip of the iceberg of over-extraction. This can be analysed using an example. Considering the investment on irrigation well and pumpset on conservative basis to be around 1600 Euros (Rs. 100,000) and considering the proportion of well failure which is around 50 percent, even if the well serves for around 5 years, at zero interest rate, the amortized cost of irrigation works to (1600/5=) 320 Euros (Rs. 20,000) per year. Usually on an average, electricity to pump groundwater is available for only four hours per day. Considering the number of rainy days in a year to be 65 days, the farmers will put on the pump for 300 days, extracting (300 days* 4hrs/day*1500gallons/hour =) 18 hundred thousand gallons or 80 acre inches of water per year. The irrigation cost without considering the cost of pumping thus works to (Rs. 20000/ 80 acreinches=) Rs. 250 per acre inch or 4.2 euros per acre inch. It is estimated that it consumes 42 kilo watt hours of electricity to pump one acre inch of groundwater[10] and approximately costs around Rs. 42 (at Rs. 1 per KWH). Thus, the total cost of groundwater including pumping cost is around 4.87 euroes per acre inch (or Rs. 292).

Macro studies however indicate that each irrigation pumpset consumes 5900 kilowatt hours of electricity to pump groundwater, which amounts Rs. 5900 per year (at Rs. 1 per kilo watt hour). Thus the electricity cost of pumping is (5900/80 =) Rs. 74 per acre inch (or 1.25 euroes). This cost of Rs. 74 forms (74/324=) around 23 percent of the total cost of groundwater of Rs. 324 (=250 + 74) per acre inch. Thus, farmers using groundwater bear a much higher proportion of irrigation cost (= 77 percent), compared to the subsidy they receive (23 percent). Groundwater farmer also has to bear a much higher cost of irrigation compared with surface water irrigation farmers.

However, this has no implication on subsidy to electricity. This only implies that it is groundwater resource which is scarce and attention has to be on groundwater management rather than on electricity. If electricity subsidy is reduced, it does not necessarily imply that groundwater extraction gets reduced. According to NSSO (2005), among those farmers using non-human energy use for irrigation, 66% used diesel pumps and only 33% used electric pumps to extract groundwater.

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[10] MG Chandrakanth, B Shivakumaraswamy, KM Sathisha, G Basavaraj, Sushma Adya, MS Shyamasundar and KK Ananda, paying capacity of farmers considering cost of groundwater and electricity in karnataka. Paper for the seminar organized by Karnataka Electricity Regulation Commission , 20th and 21st Aug 2001, Bangalore.

Conflicting estimates regarding extraction of groundwater and use of electricity for irrigation

There are conflicting estimates of use of electricity for irrigation in India. As there are no electrical meters installed to measure the electricity used by irrigation pumpsets, the use of electricity for irrigation, the groundwater pumped from wells (i.e. groundwater discharge), and groundwater recharge (which is around 5 to 15 percent of rainfall) are all estimations. And hence, precision in such estimates are still a long way to go. For instance, the recent publication by the National Sample Survey Organization indicates that considering the farmer households using non-human energy for irrigation, 66% of farmers used diesel irrigation pumpsets while 33% used electric irrigation pumpsets[11]. Accordingly the dependence on electricity is reducing and there are no compelling reasons to believe that farmers would reduce their dependence on groundwater due to vagaries of electricity supply, as there is substitutability by diesel pumpsets as well as possibility towards change in technology of irrigation such as shift to drip irrigation. Other studies confront this and indicate that electricity used for irrigation forms between 20 and 45 percent of the total supply.

Researchers working on energy-growth linkage, are not careful while using the electricity use data available from published sources in India. As indicated earlier, this data only includes estimates (but not actuals) of electricity use for pumping groundwater for irrigation. Farmers in India have not agreed for installation of electrical meters for their irrigation pumsets, and hence no metered data exists on the use of electricity for pumping groundwater. In the absence of such data, whatever conclusions researchers are drawing on electricity use in groundwater, are highly subjective on energy – water nexus.

Similarly the statistics regarding proportion of land irrigated by groundwater and surface water also varies widely across studies. The latest study by IWMI indicates that more than 80 percent of land irrigated is from groundwater[12] Study at Lawrence Berkeley Laboratoryl[13] indicates that 60 percent of the land is irrigated by groundwater. Obviously such proportions cannot increase by huge percentages in just a year. Similarly the energy used per irrigation pumpset (IP) is estimated to be around 5904 KWh per year for electrical IP set and 6638 KWh for diesel pumpset while Tushaar Shah (2009) (quoting Rao (2008)) indicates this to be 5863 KWh per hectare of irrigation per year (in AP). Here one also needs to assume that an IP set irrigates around one ha of land in a year. There is thus no uniformity in reporting the electricity use. The following paragraph from the Lawrence Berkeley Laboratory study[14] (p. 11) further complicates the issue:

> "The use of privately owned tube wells increased drastically since 1947, from about 1000 in 1947 to about 20 million today (Kelkar, 2006). In terms of fuel use, the vast

[11] Some Aspects of Farming, NSS 59th Round, (2003), NSSO, New Delhi, 2005.
[12] (http://southasia.iwmi.org/Data/Sites/15/Documents/PDF/IWMI_South_Asia_Brochure, 2005).
[13] (http://www.escholarship.org/uc/item/0f05n9cr)
[14] (http://www.escholarship.org/uc/item/0f05n9cr)

majority of pumps use electricity. There are reportedly more than 15 million electric and 6 million diesel irrigation pump sets in operation (Purohit, 2006). Pumps operated with electricity are generally preferred, due to convenience of use and the low subsidized price of electricity. The capacity of pump sets with electric motors is typically 3.7 kW, and it is 5.2 kW for diesel engines (Singh G., 1999). Operating hours are highly variable and difficult to monitor, hence we used an estimation of operating hours of 1,600 hours a year (McNeil, 2005). Using capacity and hours of use, we estimated electricity consumption, which corresponds very closely to the total electricity use reported by the CEA (0.3% difference). It is expected that the share of electric pumps will increase with increasing electrification level. By assuming that the number of operating hours of diesel pump is 20% less due to higher price of diesel, we found that approximately 44% of diesel consumption was used for irrigation. This hypothesis is consistent with another analysis (Singh G., 2006) that estimates the share of diesel consumed for pumping to be around 40%".

IWRM in AP

The field of water resources management is dominated by the government in many developing countries. Government play a dominant role in irrigation management the efforts of the governments are rarely based on any internally generated demand from the water users, in many countries government fail to create viable organizations at the local level. similar setback can be seen In the recent institutional reforms in Indian water sector. IMT (Irrigation Management Transfer) in AP and Gujrath lead to improved access to water for 15% to 25% of the farmers and extended irrigation area by 2 to 3%.
A survey of experiences in Asian countries shows that no country has successfully completed establishing new water sector policies and laws and river basin organizations, as prescribed by Bandaragoda (2006).

Low return on investment in water resource is a major concern in Indian agriculture. This is due to falling real prices of agricultural commodities and the increase in real capital costs for water resource development (Svendsen and Rosegrant 1994). There is a shift from irrigation management reforms to water institutional reforms because of the growing international interest on water, focus on the reforms at farm level and sustainable water resource management in river basin level.

Vermillion and Merrey (1998) noticed that irrigation sub sector suffered from lack of local interest. Higher-level institutional reforms were difficult to achieve than reforms in the irrigation sub-sector. With several competitive uses and users of water and with vested interests, political economy of water sector reforms is tougher than dealing with just irrigated agriculture.

APFAMGS – social capital formation

The institutions for managing groundwater resource are crucial. Ineffective institutions entail huge transaction costs. However awareness creation can reduce these costs and can have a sustainable impact. In this regard, the latest experiment by the FAO's Andhra Pradesh farmer managed groundwater system (APFAMGS) in seven drought prone districts in order to educate groundwater users with data, skills and knowledge to manage groundwater resource in a sustainable manner is an interesting example for review. This program covers more than 25,000 farmers and the assessment is based on data from around 500 communities in different economic settings. About 98 percent of the APFAMGS budget is dedicated for education and building community processes, And less than 2 percent is on supply of groundwater through recharge structures. The Andhra project has used more than 2,000 women farmer volunteers for the data collection and one third of the farmers facilitators are women. APFAMGS achieved success through collective action in project communities. The communities do not set collective targets for crop diversification or water use reduction, and the individual farmers are free to plant what they want and pump as they desire. The ultimate objective is to achieve reduction in groundwater use by the community. The reductions in groundwater draft in APFAMGS are from individual risk management decisions of thousands of farmers in the community. Here the main focus is community based management of groundwater for improving agricultural productivity, income and groundwater conservation through efficient irrigation interventions with incentives for higher profits (World Bank, 2010 Report 51676).

APWELL

The other initiatives in community based irrigation management in Andhra Pradesh are Andhra Pradesh Groundwater Borewell Irrigation Schemes (APWELL), Andhra Pradesh Community-based Tanks Management Project, and the Andhra Pradesh Drought Adaptation Initiative. The main objective is to reduce groundwater exploitation and increase its development for poverty alleviation. The key innovation is development of the concept and practice of participatory hydrological monitoring (World Bank, 2010 Report 51676).

The relative comparison of the performance of APFAMGS between project and non project areas clearly indicates that the index numbers of net returns are higher in project areas compare to non project areas proving the economic worthiness of APFAMGS (Table 4).

Table 4: index numbers of Net returns per acre from different crops in and outside APFAMGS project area, AP

Hydrological unit/type of area	Net value of outputs per acre (rupees, current year prices)	
	Base year value	Index number
Project areas: field crops		
Chandrasagar	8987	187.35
Mallapavagu	5835	169.39
Nakillavagu	6301	211.72
Narsireeddypallyvagu	8378	133.78

Erravagu	5317	132.43
Peetheruvagu	7124	106.44
Vajralavanka	9420	191.62
Non-project areas: field crops		
Nonproject areas near Chandrasagar	6415	67.78
Nonproject areas near Mallapavagu	2605	134.01
Nonproject areas near Peetheruvagu	5173	48.33

Source: Adopted from World Bank, 2010.

APWALTA

In view of the indiscriminate drilling of bore wells, the groundwater is fast depleting. Added to it, unscientific and reckless drilling has resulted in failure of bores leading to incurring heavy losses by farmers. Recurrence of drought and the drastic depletion in groundwater resource prompted the AP government to lay emphasis on efficient water conservation and management during the late 1990s and promulgated various institutions. Among these, Andhra Pradesh Water, Land and Trees Act (APWALTA) in 2002 is an unique Act unparallel to any State Governmental effort in India. This Act repealed earlier legislations such as Andhra Pradesh Ground Water Act (Regulation for drinking water purposes), 1996 and Andhra Pradesh Water, Land and Tree Ordinance. The Act empowered the State Government to appoint a state level authority, namely, Andhra Pradesh Water, Land and Trees Authority.

In 1997, Andhra Pradesh legislative assembly promulgated The Andhra Pradesh Water Resources Development Corporation Act extending to the all the River Valleys in Andhra Pradesh and other areas by notification in the Official Gazette

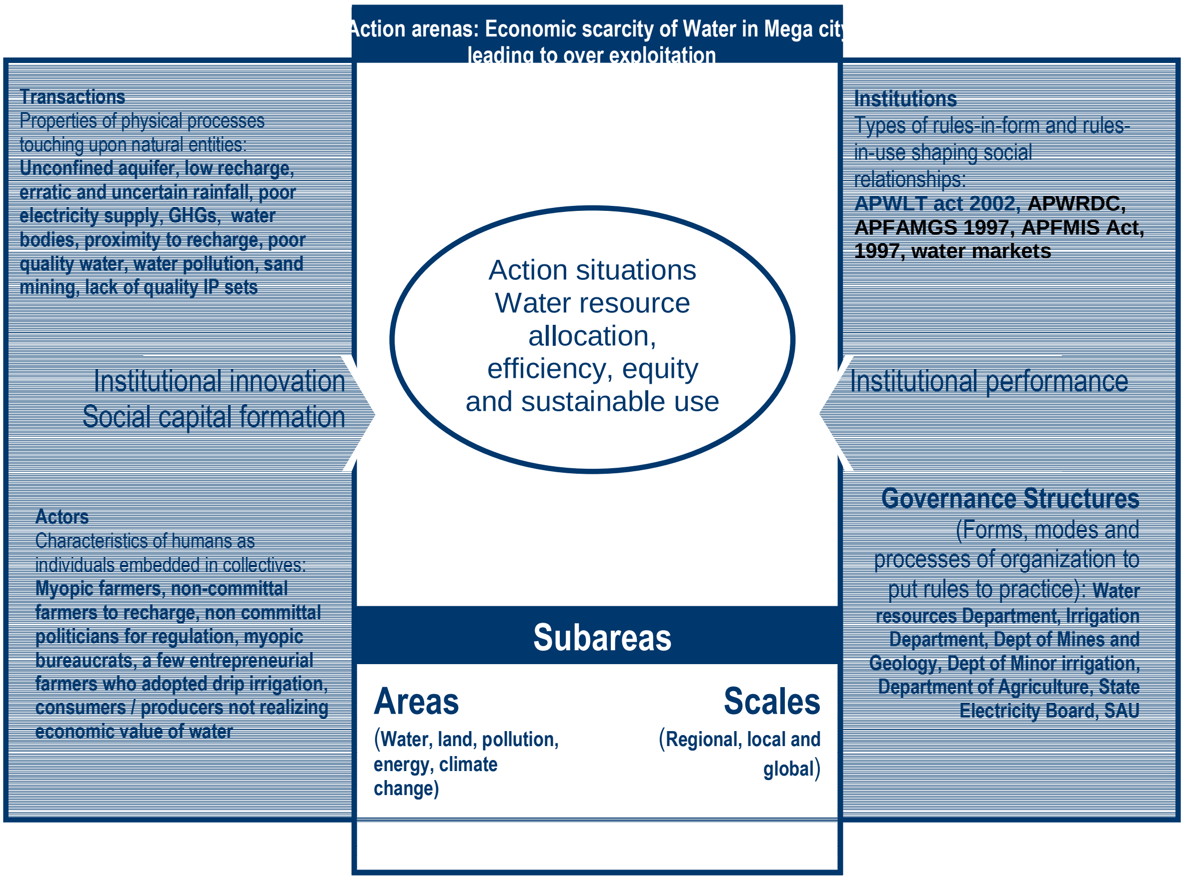
The institutions of sustainability framework

The institutions of sustainability (IoS) frame work (Hagedorn, 2002) analyzes the jointness of production specific to Agri-Environment practices. It focuses on property rights, governance structure and the actors. The property rights on ecosystem functions and governance structures for natural resources are determined by transactions and properties of actors (Hagedorn 2008).

IOS framework is a tool for improvement of sustainability as its application has a positive as well as normative aspects. Good design principles are identified based on positive analysis whose socio-ecologic interactions are more sustainable than others (Andreas Thiel, 2006). Sustainable development is searching, learning and gaining experience and the process is dynamic. The knowledge from empirical work on institutional configurations performs better in terms of sustainability than others and are effective.

In the positive sense IOS analyses existing configurations from long term process of institutional formation, which emerge spontaneously or intentionally. Institutions are interrelated rules on social aspects of life sanctioned by members of a society which maintain relationships among individuals, social and ecological systems. They interrelate actors, socio-ecological transactions, governance structures and property rights. The IOS framework is applied to the groundwater predicament which is treated as transaction (Fig 4)

Fig 4: Institutions governing groundwater use efficiency for climate change



Source:https://www.agrar.hu-berlin.de/struktur-en/institute-en/wisola-en/fg-en/ress-en/forschungskonzep-en/IoS-en/

In order to implement the institutions the following organizations need to appreciate, understand and implement the groundwater institutions (Table 5)

Table 5: Organizations monitoring groundwater resource in India

Level	Organisation	Main functions

Central Groundwater Development & Management	Central Ground Water Authority	Established in 1997, following Supreme Court orders, mainly to regulate, control, manage, and develop groundwater resources in the whole country and support states
	Central Ground Water Board	Established in 1950 for dedicated groundwater research and monitoring, to support overall planning for development of groundwater resources and to provide support to states
	Central Pollution Control Board	Norm setting on industries' water use and wastewater discharge
	Ministry of Commerce and Industries	Policy decisions and water use norm setting on water related to industry
	Ministry of Environment and Forests	Planning, promotion, coordination, and overseeing implementation of environmental and forestry programs and implementing the Environment (Protection) Act 1986
	Ministry of Rural Development	Rural development, land resources, and drinking water supply
	Ministry of Urban Development	Implementing the nationwide Jawaharlal Nehru National Urban Renewal Mission, with significant interventions in water supply, sewerage and sanitation; Water supply and sewerage for the National Capital Territory of Delhi and the Union Territories
	National Water Board	Established in 1990 under Ministry of Water Resources, apex organization with responsibility for progress achieved in implementation of National Water Policy and other issues, reports to National Water Resources Council
	National Water Resources Council	Established in 1983 with prime minister as chair, minister of water resources as vice-chair, and concerned Union ministers/ministers of State, chief ministers of all states, and lieutenant governors of union territories with secretary of Ministry of Water Resources as member secretary
	Ministry of Water Resources	Setting policy guidelines and programs for development and regulation of the country's water resources, but functions specific to groundwater resources through Central Ground Water Board
	Oil and Natural Gas Commission	Member of Central Ground Water Authority and supplements deep well logging information
Central Financing Institutions	Rural Electrification Corporation	Development financing institution that finances and fully coordinates and oversees Special Project Agriculture

	National Bank for Agriculture and Rural Development	Responsible for refinancing and standardizing substantial part of private sector groundwater
State	State electricity boards	Single window to individual farmers for obtaining pump set energization
	State government departments	Principally responsible for groundwater use and control, as water is primarily a state subject
Local	Panchayats	Rural water supply, but to be devolved more water services and water resource management functions

Source: World Bank, 2010

NEGATIVE EXTERNALITIES

The water use efficiency is computed by first estimating the negative externality in well irrigation. The negative externality is the difference between the amortized cost of irrigation per functioning well minus amortized cost of irrigation per well (H Diwakara and MG Chandrakanth. 2007). The hypothesis is that if all wells on the farm are functioning, then there is no externality and hence the amortized cost per functioning well will be the same as amortized cost per irrigation well (which includes both functioning and non functioning wells). If the farm has both functioning and non functioning wells, then, depending on their respective proportions of investments lost, the negative externality varies. The negative externality is at least around Rs. 10,000 per irrigation well per annum in the hard rock areas.

Water use efficiency

Water use efficiency is measured in terms of crop output and net revenue realized per unit volume of water used by farmers. For those farmers who use drip irrigation, the water use efficiency is higher as they realize higher output per unit volume of water compared with conventional irrigation (or flow irrigation) farmers. This further has ramifications on increasing the resilience of farmers in the wake of well failure and thereby fight poverty, unemployment through increased income earning opportunities and the resulting social capital formation. The water use efficiency is also reflected in the net return per acre of land. In the case of drip irrigation, the water applied will be low and hence the output per unit volume of water will be high.

COST OF WATER AND WHO BEARS IT

With the increasing negative externality among irrigation wells in the hard rock areas, which constitute around 60 percent of India's area, the groundwater farmers bear at least 75 percent of the cost of water for irrigation and through the electricity / power subsidy the State bears around 25 percent of the cost of water. But in the case of surface water, the state bears the full cost of water, which is a total subsidy.

A simple back of the envelope calculation reveals this. Usually an irrigation well draws around 100 acre inches of groundwater in a year and irrigates around 2 acres of land. A typical irrigation bore well costs around Rs 0.2 million (including the cost of well failure weighed with well failure probability) and serves for around 5 years (on a non-conservative basis). This is the individual farmer's private investment in irrigation. Thus, even considering at zero rate of interest, the farmer bears atleast Rs. 40,000 per year as the cost of irrigation which includes a negative externality of Rs. 10,000. Considering that the State bears the cost of power to lift groundwater which is around 50 kilo watt hours per acre inch, this amounts to 5000 kilo watt hours per year valued at Rs. 2 per kilo watt hour is worth Rs. 10,000 per year. Thus the State subsidizes to the extent of Rs. 10,000 per irrigation well. Thus the total cost of groundwater is Rs. 50,000 per year per irrigation well spread over 100 acre inches, which amounts to around Rs. 500 per acre inch (Chandrakanth, Bisrat and Bhat (2004), Chaitra and Chandrakanth (2005), Manjunatha (2005), Varuni, Chandrakanth, Nagaraj and Srikanthamurthy (2006); Seema, Chandrakanth and Nagaraj (2008); Shalet et al (2008), Thamanadevi (2008); Priyanka (2009), Mamatha (2009) and Vikram Patil (2009).

In the case of surface water, the entire cost is born by the State. According to study in the Bhadra command area of Karnataka, the surface water costs around Rs. 600 per acre of paddy, Rs. 1200 per acre of sugarcane and Rs. 120 per acre of semi dry crops (Nagaraj, Shankar and Chandrakanth, 2003). Thus, 100 percent of the cost of surface water for irrigation is borne by the State in India, while farmer bears 75 percent of the Groundwater cost in India. Thus the relative economic efficiency of groundwater farmers in relation to surface water farmers.

Collective action in the wake of externalities to improve economic efficiency

In the megacities environs, the periurban agriculture faces severe water crisis due to increasing competitive uses for water and especially groundwater. A few innovative farmers have shifted to drip irrigation as the mode of water application, which substantially saves water extraction, thereby enhances the life of irrigation wells, income, employment, resilience and reduces externalities due to cumulative interference among wells. Can such an action by a group of farmers be considered as a collective action? The history of micro irrigation in India indicates that at first drip irrigation technology was used for broad spaced commercial perennial crops like grapes, coconut, arecanut, vanilla, banana, pomegranate, sapota, Later on it spread to sugarcane (Maharashtra), mulberry (Karnataka). Currently it is spreading to vegetable and food crops such as tomato, potato, gourds, maize, and wheat which are narrow spaced crops. The estimates of water saving in different crops due to drip irrigation are provided (Table 6).

Table 6 : Area under micro irrigation across crops in Karnataka

Sl. No	Micro irrigation	Current area (ha)	Potential area (ha)	Drip/ sprinkler cost (Rs/ha)	Subsidy level (%)	Yield increase (%)	Water saving (%)
Crops under Drip irrigation							
1	Coconut	65852	131704	58442	50 to 70	25	33
2	Arecanut	38717	77434	35000	50 to 70	30	38
3	Mango	6286	9504	25000	50 to 70	25	40
4	Grapes	3983	12106	44000	50 to 70	45	40
5	Sapota	1139	2619	35000	50 to 70	42	48
6	Mulberry	28767	47180	43400	50 to 70	36	42
7	Tomato	1542	7713	34000	50 to 70	10	56
8	Potato	480	1923	40500	50 to 70	15	30
9	Pomegranate	4367	10000	35000	50 to 70	30	40
Crops under Sprinkler irrigation							
1	Bajra	990	2476	25000	50 to 70	19	56
2	Cabbage	88	222	30000	50 to 70	3	40
3	Chilies	860	2150	35000	50 to 70	24	33
4	Cotton	1118	2796	40000	50 to 70	50	36
5	Cowpea	245	613	25000	50 to 70	3	19
6	Garlic	33	83	35000	50 to 70	6	28
7	Red Gram	583	1458	30000	50 to 70	57	69
8	Groundnut	4136	10341	25000	50 to 70	40	20
9	Jowar	2978	7445	25000	50 to 70	34	55
10	Maize	8940	22352	35000	50 to 70	36	41
11	Onion	1070	2676	35000	50 to 70	23	33
12	Potato	192	480	30000	50 to 70	4	46
13	Sunflower	4312	10781	25000	50 to 70	20	33
14	Wheat	2858	7145	25000	50 to 70	24	35

Source: 1. CN Priyanka, 2009, P Mamatha, 2009, Thamana Devi (2008),

These estimates clearly indicate the potential for drip irrigation to serve the dual goals of water and energy saving on the one hand and reduced GHGs on the other.

While addressing ‘asset specificity’ of groundwater in hard rock areas, institutional, neoclassical and technological strategies are in order. ‘Supply side’ technological (drip irrigation for ex) and neoclassical (water markets) solutions are slowly pervading. Institutional solutions are yet to enter hearts of farmers and planners. The results from field studies (referred in the section on Cost of Groundwater) indicate have been used in the paradigm of the Institutions of sustainability (Hagedorn 2002, already presented above) and Wade (1988) framework for sustainable management (Table 7).

Table 7: Wade framework for collection action in groundwater (1988)

wade conditions for collective action in groundwater management	High possibility	Low possibility	Impossible
I. Groundwater resource			
1. Smaller, clearly denned boundaries		√	
II. T*echnology*			
1. Higher cost of exclusion for groundwater farmers	√		
III. Relationship between groundwater and farmers group			
1. Proximity of groundwater resource to residence	√		
2. Higher demand for and more vital Groundwater is for survival	√		
3. Better knowledge of sustainable yield of groundwater			√
IV. Groundwater farmers association			
1 Relatively small number of farmers pumping groundwater	√		
2. Clearly defined boundaries for farmers overlaying aquifer			√
3. Higher proportion of farmers benefiting from groundwater conservation groundwater compared to those exploiting for privatizing it		√	
4. Greater opportunities for discussion of common problems	√		
5. Greater extent to which farmers are bound by mutual obligations so that they abide by their promises	√		
6. Larger existence of joint rules (eg. punishments for rule breaking) for purposes other than groundwater conservation			√
V. Noticeability			
1. Easier noticeability, detection of rule-breaking farmers			√
VI. Relationship between groundwater users and the state			
1. Lesser State interference in collective action		√	

CONCLUSIONS AND RECOMMENDATIONS

Considering IoS and wade frameworks, there is thus, dire need for the State for effective and implementable groundwater regulation incorporating the technological and institutional solutions. Thus, the water policy needs to focus on the following major issues concerning surface water and groundwater:

1. Technical improvements to irrigation infrastructure
2. Technologies of water utilization
3. Institutional innovations
4. Irrigation extension

The details of policy are as under:

I. Technological improvements to irrigation infrastructure include:

1. Lining of irrigation canals – to prevent seepage losses
2. Canal alignment - filling cracks and crevices as well as aligning them
3. Silt removal in canals
4. Weed removal in canals
5. Filling irrigation tanks in the series from canal net work
6. Plugging leakages in canals
7. General periodic maintenance
8. Public Lift irrigation schemes - to be equipped with technically efficient standard pumpsets
9. Removal of encroachments of tank beds
10. Cleaning water ways to irrigation tanks
11. Desilting irrigation tanks
12. Conversion of irrigation tanks to percolation tanks wherever feasible
13. Promoting conjunctive use of tank and well water
14. Strengthening tank bunds and tank maintenance
15. Raising tank bunds and increasing tank capacities wherever feasible
16. Canal alignments of irrigation tanks
17. Watershed development programs to enhance recharge

II. Technologies of water utilization

1. Changes in crop pattern in line with the project
2. Improvements in drainage for reducing the extent of water logging, salinity, alkalinity
3. Soil amendments
4. Changes in methods of irrigation - land leveling, transfer of water through HDPE / LDPE, PVC pipes, sprinkler / drip / micro irrigation
5. Aerobic rice / System of Rice Intensification
6. Crops varieties suitable for different methods of irrigation

III. Institutional innovations

1. Water Users Association (covering surface water and groundwater)
2. Warabandi (Rotational system of water use and allocation among farmers located at different reaches of the canal system)
3. Bringing IWRM in water policy down to executive works
4. Fixing time targets to complete infrastructure works (to avoid cost over runs)
5. E tendering, E governance of all works including O and M
6. Transparency in irrigation administration and execution of works
7. Promoting water markets wherever feasible
8. Farmer to have not more than one functioning irrigation well irrigating not more than two acres, to enable equitable and efficient water sharing.

9. Extension of benefits of developmental programs to farmers who have adopted water use efficient technologies
10. Water log: maintenance of all statistics relating to surface water, groundwater in all sources, the availability, utilization, number of users, crop areas, volumetric and linear estimations of water use, at both farmer and village level

Irrigation Extension service:

The Department of Agriculture to create an additional fleet of agricultural officers or add irrigation extension work in addition to their regular extension work to educate farmers in water use efficiency methods. Without creating substantial awareness among groundwater irrigating farmers, any institutional reform concerning groundwater regulation will meet greater challenges than acceptance by the farming community. This is due to the fact that groundwater farmers are bearing at least 75 percent of the groundwater cost even considering subsidized or 'free' power to farmers. The cost of negative externality due to well failure, an implicit cost borne by farmers is much higher than the electricity subsidy they receive. Hence capacity building and creating awareness regarding sustainable use of groundwater is the prerequisite for any institutional innovation concerning groundwater regulation in hard rock areas of India.

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