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Groundwater Markets and Agricultural Development: A South Asian Overview

Tushaar Shah

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भूमिगत जल बाजार और कृषि विकास: दक्षिण एशियाई अवलोकन
Groundwater Markets and Agricultural Development: A South Asian Overview

तुषार शाह
Tushaar Shah

NABARD

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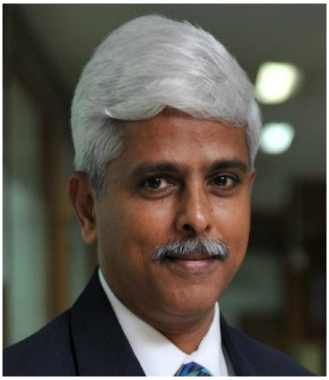
Foreword



There is a vast body of research available on topics related to agriculture and rural development in the academic world. But, most of it is in the technical realm and not in a form which could feed into the policy. Research must first lead to better understanding of a subject and then into a robust policy, wherever it can, so that it touches the multitude of Indians across the length and breadth of our country through better public policy and efficient services. Discussion with my colleagues on this issue lead to this new series "Research & Policy". We wish that this series will provide the breadth and depth of research into an area topped up by a lucid presentation for the policy makers.

I am happy to present the eighth publication in this series on the South Asian experiences of groundwater markets and agricultural development, written by Dr. Tushaar Shah.

I wish this new series acts as a bridge between the researchers and policymakers.

P. V. S. Suryakumar
Deputy Managing Director

Preface

Agriculture sector proved a silver lining in the pandemic period registering a positive growth in the covid times. Yet it faces various structural challenges to be addressed to make it profitable. For, the majority of the population is still dependent on the sector. As we all know, investing in research is one of the best strategies to address problems of agriculture. Equally important is to communicate the research findings to policy makers to design and tweak policies that matter. During one of our meetings with Shri P. V. S. Suryakumar, our DMD, we had loud thinking if we can commission a few review papers on select themes. We thought that it is appropriate to request veteran scholars who spent prime of their life on a given research theme to attempt such a work where they will distil their understanding and the research done on the theme in a short paper. Duly encouraged by DMD and our Former Chairman, we wrote to a dozen eminent scholars. And the response was overwhelming resulting in Department of Economic Analysis and Research (DEAR), the research wing of NABARD, initiating the "Research and Policy" series. The motivation is, thus, to get a few handles from research that can help effective policy intervention. This series will be useful to policy makers and researchers alike.

The "Research and Policy" series is an attempt to get a glimpse of hardcore research findings in a capsule form thereby making it more effective and communicative to policymakers. The group of researchers who agreed to prepare a review of research have spent their life in the field of agricultural research. Our purpose here, as we communicated to them, was not just to get literature survey but to get researcher's heart and their experience which they gained during their long passionate innings. The paper is expected to highlights various issues, policy relevance, prescription, and suggestion for future papers on the themes of interest to NABARD.

Water touches every aspect of human life from drinking and sanitation, to agriculture and energy production. Unfortunately, for the majority of the world's population, water scarcity has become a major concern with impacts seen across communities, economies and nature. Apart from supply-side infrastructure such as reservoirs and canals, mechanism such as water markets can prove vital for alleviating water scarcity, restoring ecosystems and driving sustainable water management. In view of this, the current paper on the South Asian experiences of groundwater markets and agricultural development, written by Dr. Tushaar Shah, Professor Emeritus, Institute of Rural Management Anand, Gujarat, assumes importance. Dr. Shah has a distinguished academic career, with research interests in farmer organisations and water institutions and policies.

The paper begins by examining the equity and availability of groundwater irrigation access across the country, and sheds light on how various policies and norms have distorted the sustainable use of groundwater. It then describes how infrastructure, as well as social, topographical, and economic factors, influenced the rate of development of a region's water markets. While discussing the factors for the development of water markets, the author thoroughly examined their efficiency as an institution and their role in promoting efficient resource allocation. Finally, the author discusses important distinctions and commonalities in groundwater markets around the world, along with different policy instruments and strategies for the sustainable groundwater management.

In bringing this series as planned, we would like to express our sincere grati-tude to Dr. G. R. Chintala, Former Chairman, NABARD for his inspiring leadership, unstinted support and guidance. We also wish to express our sincere thanks to Shri P. V. S. Suryakumar, DMD, for being the inspiration and the driving force behind the publication of this first of its kind series. We are grateful to the authors of this series who agreed to write on themes relevant to NABARD in such a short period of time. Indeed, it has been a great privilege for us.

I also acknowledge the contributions of the officers of DEAR, NABARD especially Dr. Vinod Kumar, GM; Dr. Ashutosh Kumar, DGM; Mrs. Geeta Acharya, Manager; Ms Neha Gupta, Shri Vinay Jadhav, Assistant Managers, and others who coordinated with the authors and the editor to bring out the series as envisaged.

Thanks are due to Dr. J. Dennis Rajakumar, Director, EPWRF and his team for their contribution in copy editing and bringing uniformity to the document.

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Acknowledgement

Over his nearly 40-year association with research on South Asian water markets, the author has benefited enormously from numerous co-workers, critics, readers, field researchers, data collectors, collaborators, discussants and commentators, and others. Early supporters who kept inspiring this body of work included Robert Chambers, M L Dantwala, A Vaidyanathan, B D Dhawan, Y K Alagh, David Seckler, Deep Joshi, Anil Shah, Kamla Chawdhury, Marcus Moench, Janakarajan, K V Raju, Vishwa Ballabh, Navroz Dubash, K Palanisamy, D Nagabrahmam, Katar Singh, Shashi Kolavalli, R N Haldupur, P S Appu, Anthony Bottral, Rolf Mueller, M S Mandal, Mary Tiffen, Richard Palmer-Jones, Bill Bentley, Norman Uphoff, James Copestake and many others. Over the years, many younger scholars advanced the field and enriched its corpus of ideas and evidence. Notable among these were Aditi Mukherji, Avinash Kishore, Shilp Verma and a generation of young researchers who had spent varied terms at the IWMI-Tata Water Policy Programme that I founded and led during 2000-2019. Many of them worked on various aspects of water markets and contributed valuable new evidence. While it is impossible to point out the contributions that each made, this is to acknowledge that the growing literature this paper surveys had imprints of all these.

Tushaar Shah
Professor Emeritus
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List of Box

Abbreviations

BCM	Billion Cubic Meter
CGIAR	Consultative Group of International Agricultural Research
CGWB	Central Groundwater Water Board
dWEM	diesel Water Extraction Mechanism
eWEM	electric Water Extraction Mechanism
FR	Flat Rate
GWMs	Ground Water Markets
HP	Horse Power
HYV	High Yield Varieties
IRMA	Institute of Rural Management Anand
IWMI	International Water Management Institute
m ha	million hectare
mham	million hectare meter
NGO	Non-Governmental Organisation
PMKSY	Pradhan Mantri Krishi Sinchai Yojana
SKY	Suryashakti Kisan Yojana
TERI	Tata Energy Research Institute
US	United States
WEMs	Water Extraction Mechanisms
WS	Water Scarce

Executive Summary

In seeking efficiency, equity and sustainability in surface and groundwater management, developing countries have tried public management, administrative regulation, farmer groups and co-operatives but with only limited success. A growing debate on water markets has opened up new directions in thinking about water resource management and governance. Interest in South Asian groundwater markets has been fuelled by their spontaneous emergence and rise to a position of centrality in agrarian economies and their wide-ranging efficiency and equity impact. In the western United States (US), New Mexico and Chile, emerging trade in surface water may well assume a significant allocative role in the region's water resource management. In countries like Peru and Mexico, legal frameworks are being created inter alia to promote water markets. In several cities and towns of Africa and South Asia, water markets already serve urban domestic water demand.

South Asian debate has been dominated by what are best described as markets in pump irrigation service. The seller has no well-defined ownership of water, which he uses to water his neighbour's crop. He may well pump water underneath the neighbour's land and still charge the latter for the service. The reason why these markets have spontaneously emerged is the unequal ownership of modern water extraction mechanisms (WEMs). A related reason is extreme land fragmentation making it well-nigh impossible to install a tubewell and motor pump in all parcels of a small farm holding. Typically, owners install WEMs in one or two of their largest parcels and buy irrigation service from nearby WEM owners in others.

Water markets in the US, Australia and Chile, in contrast, are markets in tradable water rights. These arise from the legal foundations of water governance in those societies, where water abstraction is registered and licenced to users with quantitative quotas. Water markets in the west are a central mechanism of direct water governance. Irrigation service markets that are referred to as water markets in South Asia are a central mechanism for indirect water governance.

South Asian water markets have the potential to move water from low to high value uses, to promote investment in increasing the efficiency of water use, and to transform water from being a 'scarce but free' resource into an economic good with an

opportunity cost. The South Asian experience has shown that groundwater markets have opened up new livelihood opportunities for the poor, who would be worse off in their absence. Groundwater markets have also created new powerful instruments for public policies to influence millions of pumpers and their water buyers. On the flip side, groundwater markets exacerbate the problems of over-exploitation in areas with fragile groundwater ecology. Either way, understanding their working is central to formulating effective public policies in water resource sector.

Early studies on groundwater markets were inspired by a clutch of questions about their role and characteristics: what explains differences across regions in the development of decentralised, informal water markets? What determines the breadth and depth of water market transactions in different geographies? How do terms of water trade get determined? What are the productivity and equity impact of the working of water markets? How does water scarcity circumscribe the functioning of this institution? Do water markets exacerbate over-development of water resource?

The current global debate on water-energy-food nexus owes its origin to South Asian water market research which put into bold relief, for the first time ever, the complex relationship between energy pricing and the economics of groundwater irrigation of food and cash crops. Water market studies showed how flat pricing of farm electricity supply created buyers' water markets that benefited marginal farmers and tenants, while metered power supply had the opposite effect of catalysing sellers' water market. These studies also focused on the emerging contradictions in the South Asian groundwater economy. Eastern parts of India, with abundant groundwater supply but poor progress in rural electrification, witnessed highly exploitative water markets in which small farmers were obliged to over-economise on water, simply because they had to use expensive diesel to pump groundwater. In contrast, the entire western corridor of India has spawned buyers' water markets made possible by free or subsidised or unmetered farm power supply. This contradiction is at the root of India's groundwater crisis. Our 'diesel divide' has led to under-utilisation of groundwater in much of eastern India where it is abundant, and to over-exploitation of this resource in semi-arid western India where resource scarcity is at odds with its buyers' water markets offering irrigation service at a price way below the socio-ecological cost of water.

In this review paper, we assess the conceptual and empirical materials developed over nearly 40 years of research by water-market researchers from several countries, particularly from South Asia. Our aim is to analyse the role that water markets can play as a co-ordinating mechanism in water management, and how national policies and priorities could strengthen or weaken this role.

Groundwater Markets and Agricultural Development: A South Asian Overview

Introduction

For a long time in South Asia, water policy and governance debate were dominated by technocratic (modernisation of irrigation systems) and administrative/institutional alternatives (such as water user associations in canal commands) because of the absence of people's institutions for water development and appropriation in most countries. Emergence of market institutions in ground as well as surface water in different parts of the world have begun to change the tenor of this debate. Two distinct strands of water market debate have emerged: the South Asian discussion has focussed largely on markets in groundwater irrigation service and their role in diffusing access to groundwater irrigation to the resource poor (Shah 1993; Mukherji 2007; Saleth 2014; Kumar *et al.* 2004), and in contrast, much western discussion (focussing on America, Australia and Chile) on trade in water rights has been influenced by the potential value of market institutions in converting water into an economic good, in shifting it from low to high value uses, and in promoting investment in water production and conservation (Rosegrant and Gazmuri 1994). The South Asian discussions has learnt from the already existing vibrant groundwater markets in Bangladesh, Pakistan, Nepal and India, and has focussed upon indirect policy instruments – such as electricity pricing and supply policies, purposive tax-subsidy policies, etc. – to influence their working to achieve public policy goals in different aquatic environments. In contrast, the western debate is concerned with how best to catalyse markets for rights in surface and groundwater, and therefore, focussed on creation and specification of property rights considered necessary to spur the rise of markets.

In this review paper, we focus primarily on analyses of South Asian groundwater markets (GWMs) based on papers published mostly over 1985-2020 period. We begin in Part I with a discussion on several aspects of the South Asian GWMs, its complex political economy, and its rapid emergence at the centre-stage of the region's agrarian economy. Part II analyses the functioning of GWMs as an economic institution. In part III, we explore ways of using GWMs as indirect instruments of achieving public policy goals. We conclude by exploring the common ground between the South Asian debate on GWMs and the discussions on water markets in Western United States and Latin America.

Part I

Political Economy of Groundwater in South Asia

Equity in Irrigation Access

Since the 1970s, groundwater irrigation has made a steady ascent to a position of centrality in many agrarian economies in Asia. Consider, for instance, the case of India. India had an estimated 47.5 million hectare meter (mham) of known groundwater potential during the late 1980s (Padmanabhan 1988). Nearly half, very likely some 22-26 mham, was already being used in the 1990s to irrigate about 42-45 million hectare (m ha) of land. While the estimate of available resource has remained largely unchanged, the area served by groundwater has rapidly increased. In 2017, the Central Groundwater Water Board (CGWB) estimated the total annual recharge to be 43 billion cubic meter (BCM) and usable groundwater resource to be 39 BCM. The CGWB (2017) estimated annual draft to be 23.9 BCM, that is, about 63% of the available resource. At a rate of 0.60-0.65 meter per ha,[1] the ultimate irrigation potential with groundwater was envisaged to be around 70-80 m ha. By 2020, India was very close to this target with number of water extraction mechanisms (WEMs) rising at a break-neck pace of 1.5 million per year. Much of South Asia is facing similar free-for-all in groundwater exploitation with inequity in irrigation access growing in tube well dominated areas (Kuriachen *et al.* 2021). From the equity point of view, a critical question that has dominated South Asian discussion for 50 years is: who will claim what remains of this valuable resource, the haves or the have-nots? And, how can the local elite use control over groundwater to force the poor and the weak into an unequal relationship (Naz 2015; Sugden 2014; Rawal 2002).

The equity question was largely irrelevant to groundwater irrigation 50 years ago. In the pre-1960 era, bullock bailers mounted on open dug wells fetched just enough water to protect a crop from moisture-stress; also, nothing more was needed since intensive irrigation was seldom used. But the simultaneous rise of the Green Revolution crop technologies and the modern tube well technologies in the 1960s made possible quantum jumps in the income per acre of intensively irrigated land. Compared to alternative irrigation sources such as tanks and canals, tube well irrigation offered advantages of greater control over water application. Both tube well owners and buyers of tube well water began obtaining significantly better crop yields and land use intensities, compared to farmers' dependent on other irrigation sources (Dhawan 1985, Rao 1973, Kolavalli 1986; Lowdermilk *et al.* 1978; Shah *et al.* 1996a; Shah *et al.* 1996b).

In the basins of Indus, Ganga and Brahmaputra, there is the densest concentrations of rural poverty over-lying some of the world's richest aquifers, and this combination offers a big opportunity for improving the livelihoods (Kahnert and Levine 1993). During the 1950s and 1960s, the policy response to this opportunity took the shape of state tube well programmes, support to non-governmental organisation (NGO)-sponsored group tube wells, and a variety of subsidy programmes – all of which had aimed at enhancing poor people's access to groundwater. The nature of subsidy programmes had differed across regions. In groundwater-rich Bangladesh and eastern India, government policies had aimed at flooding the countryside with deep tube wells, shallow tube wells, low lift pumps, hand tube wells and treadle pumps through subsidies to individual farmers and landless groups, and through renting government-owned tube wells to private operators (Mandal 1989; Morton 1989; Mukherji *et al.* 2021). In western and southern India, where groundwater resources are limited and electricity supply conditions better, government support had taken the form of subsidised electricity supply. Keeping this in view, scholars were engaged with a question of whether these policies really served their purpose. Are there ways to minimise the distortions they cause? Are there better ways of enhancing small holders' access to groundwater irrigation? Rawal (2002) discusses cases of two villages in West Bengal that use non-market rules to do this. But is it possible to do this on a large scale commensurate with the ubiquity and pervasive nature of groundwater irrigation? Responding to these issues has been complicated by a host of externalities associated with groundwater development.

Externalities

In regions with limited and/or over-exploited groundwater resources, the critical issue is how to make groundwater irrigation sustainable, where possible, in an equitable manner. Each modern WEM creates its own 'area of hydrological influence' below the ground surface and an 'area of socio-economic influence' above it, both together generating a complex web of externality and equity impacts (Dhawan 1990; Moench 1992 and 1993; Shah 1993:128-153). These impacts have a great deal to do with the way property rights on groundwater are traditionally held and enjoyed. Groundwater is a common property until it is extracted, whereupon it instantly gets privatised. In South Asia, a land owner can be viewed to own the aquifer overlain by his land but only in principle. In reality, however, the right to groundwater is assumed or denied only through the ownership of a WEM. A land owner can, thus, establish virtual private property rights over all the groundwater s/he can extract, even if the water pumped is drawn from underneath the neighbour's land (Planning Commission 2007). Deep tube wells with large radii of hydrological influence do precisely this. Early owners of tube wells in a village typically acquire control over groundwater reserves overlain by land belonging to several owners, and this control is reinforced by siting norms that prevent neighbouring latecomers from sinking tube wells in a radius of 500 meter (m) around the first-comer. If neighbours bribe their way out of the siting norms, there emerges the problem of well-interference and all the WEMs being pumped at the same time suffer reduced yield. Owners of shallow open wells are the worst sufferers in this process, and their wells turn dry except during the off-season when irrigation is not needed anyway (Shah 1993).

Many groundwater externalities are self-fulfilling. The inflictor himself is amongst those who get hit. Often, the inflictors have enough information to predict the consequences, and yet in the absence of mechanisms for collective restraint on pumping, they fail to internalise these externalities and get driven to socio-ecological crisis (Shah 1993:138-9). Then, only some of the externalities imposed by modern WEMs are reciprocal and many are unilateral (Janakarajan 1994). Dhawan has documented the drying up of thousands of dug wells in north Indian plains as a result of the tube well revolution (Dhawan 1982). Bhatia (1992) has offered similar statewide analysis for Gujarat. Many other scholars have in recent times explored these issues through micro-level studies: for example, Rao (1993) for two watersheds in Kolar district of Karnataka; Kumar and Patel (1995) for the Kheralu block in North Gujarat; and Janakarajan (1995) in Madurai district of Tamil Nadu. In much of the hard rock peninsular India, draw-down externalities have already acquired worrisome dimensions, and even in groundwater-rich Bangladesh, draw-down externalities and well-interference have become important in up-land areas especially in years of insufficient rainfall (Mandal 1989).

With the growing tradition of intensive well irrigation and accelerating rate of overall water-draft, water tables begin to decline on a permanent basis in many areas, thus lowering pumping depths and raising pumping costs. In north Gujarat and Tamil Nadu in India, and Sindh in Pakistan, modern WEM owners are, as a result, left chasing perpetually declining water tables leading to competitive deepening of wells. In north Gujarat, which has acquired notoriety for groundwater overdraft by private pumpers, productive tube wells may be over 1,200 feet deep needing capital investment of well over $20,000 – far beyond the capacity of even large farmers, thereby, ruling out any possibility of smallholders getting direct access to groundwater on their own (Bhatia 1992; Kumar 1994; Shah and Bhattacharya 1993). In fragile coastal ecologies, where sea water is overlain by freshwater aquifers, overdraft induces saline intrusion imposing massive, irreversible ecological destruction. Saurashtra region in Gujarat and Minjur aquifer in Tamil Nadu offer living examples of such devastation. Other problems of declining water quality on account of pollution and rising fluorosis content in western India and arsenic content in parts of eastern India offer yet another intractable policy challenge, especially as competition among irrigation, industrial and domestic uses become acute in many regions (Moench 1994b; Shah and Ballabh 1995). In such areas, key policy priorities have been to minimise draw-down externalities, aquifer mining and permanent decline in groundwater tables, as well as a host of associated environmental problems of salinity, alkalinity and deteriorating water quality in general. Many governments have tried administrative regulation of groundwater development through siting and licensing norms, and selective controls over credit and electricity connections for WEMs. However, these measures have proved ineffective when not retrograde (Dhawan 1989; Moench 1994a and 1994b; Shah 1993).

Equally ineffective have been the government programmes to stimulate groundwater irrigation in vast areas where it can create large positive externalities. In the commands of canal projects, too much water too close to the ground surface presents major ecological and economic hazard. Estimates of water-logged areas in the South Asian region vary enormously, and they are placed at around 6 m ha in India.[2] Good examples of the ecological and economic damage caused by too much groundwater are the command areas of Sharda Sahayak, Gandak and Sone commands in eastern Uttar Pradesh and north Bihar (Shah *et al.* 1996a; Shah *et al.* 1996b). Even 50 years ago, these areas were flood-prone, and had high water tables, and construction of several large diversion canal systems had steadily raised water tables in these plains reducing the capacity of the water table aquifers to absorb the annual floods. As a result, vast areas face surface waterlogging for 4-5 months following the monsoons every year. The result is large and growing stretches of the so called *usar* lands, substantial decline in kharif crop output and a variety of health hazards (Shah *et al.* 1996a). What many of these areas, where groundwater salinity is low or where blending saline with fresh water is possible, need the most is effective vertical drainage that heavily pumped wells could provide. Since private investment in groundwater exploitation in commands of new canals picked up only some years after the system is commissioned, planners seldom took into account the substantial indirect benefits of canal irrigation by recharging wells in the command. The studies by Dhawan and Satya Sai (1994 of Mula command, Shah's study of Mahi-Kadana (1991) and Meinzen-Dick's (1994) study of Sone command point to the tremendous scope for more optimal husbanding of ground and surface water resources in small watersheds and in large river basins.[3] Rapid groundwater development in these regions can cause large positive externalities by reducing flood loss and treating saline and alkaline lands. The GWMs are potentially a powerful policy instrument for managing externalities of unregulated groundwater development.

Public Policies

The repertoire of public policy instruments currently in use for managing groundwater resource in South Asia's diverse conditions is unequal to the criticality of the challenge of efficient, equitable and sustainable water resource management. Leave alone improving things: these policies often leave them worse, especially for the poor.[4] Moreover, the design of the existing regulatory and promotional framework is oblivious of the intricate dynamic of localised water markets. Consequently, even when these norms are enforced, preventing the establishment of new WEMs in the neighbourhood of an existing one usually strengthens the monopoly power of the water sellers that often takes the form of exploitative prices and arbitrary behaviour on the sellers' part.

Far more stringent spacing norms are used around public tube wells, which have a larger 'design' command than they actually serve. Private tube wells are forbidden in the design command, establishing complete monopoly of the public tube well. Considering that most public tube wells are out of commission most of the year due to poor maintenance and repair and operator absenteeism, farmers within public tube well commands are often worse off compared to those outside. Poor enforcement of official norms offers some respite from this tyranny of public monopoly. In Gujarat, private WEM owners operating from the fringes easily reach out to the forbidden fields through underground pipelines, eroding the market share of the public tube well (Asopa and Dholakia 1983).[5]

Over the years, the overall efficacy of administrative regulation has declined even further because the public sector presence in groundwater irrigation has become marginalised, though dominant a few decades ago. In Pakistan and northern India, for instance, public tube wells dominated the groundwater scenario until the early 1950s, but have since been overwhelmed by private WEMs in sheer numbers as well as reach. At the South Asian level, of the nearly 30 odd million WEMs in use at the beginning of the new Millennium, less than 100,000 were state tube wells, and except in Bangladesh, NGO-managed group tube wells too are insignificant in number. Moreover, the dominance of private WEMs in the groundwater economy has got further levered through spontaneous emergence almost everywhere of groundwater market (GWMs) by which each WEM owner sells pump irrigation service to several neighbouring farmers.

Mukherji (2008b: 1077) estimated that in India, “the area irrigated through pump irrigation services has increased from an estimated 1.0 million ha in 1976-1977 to an estimated 20.0 million ha in 1997-1998”, growing further to 60-70 million ha by 2018-19. For a long time, it was thought that GWMs were far better developed in western India compared to the east. However, the analyses by Mukherji *et al.* (2008) also call into question two myths prevalent in literature: that these markets were under-developed in eastern India in the 1970s and 1980s, and that in recent times, they are shrinking in southern peninsular India due to groundwater depletion (Mukherji 2008b). Due to the complete lack of appreciation on the part of water bureaucracies of the working, impact and immense power of these informal self-organising water markets, governments have become increasingly irrelevant in the groundwater economies.

Part II

Dynamics of Groundwater Markets

In sum, groundwater already accounts for between 1/2 and 3/4th of South Asian irrigation – well over 95% of the area served by groundwater is commanded by privately owned wells. Also, a good deal of private groundwater irrigation occurs through the sale of pump irrigation service by private WEM owners to their neighbours under a variety of contractual arrangements. Markets of sorts in canal water too are reported in many countries; however, these are relatively nascent, and will be understood better as more evidence becomes available. In contrast, localised, fragmented and informal markets in lifted water, primarily from wells, tanks, streams, canals and rivers, already have far reaching social effects. In South Asia, some 18-20 million owners of modern WEMs (that is, open or borewells mounted with diesel or electric pumpsets) are probably involved as sellers, and some 25-30 million or more may well be buyers. Together, they have wrested control over large and growing segments of the national irrigation economies from governments. In water abundant areas, water markets are socially beneficial compared to autarky, even when they are monopolistic. The beneficial impact multiply where water markets are competitive and efficient. On the contrary, competitive water markets contribute to resource depletion and need to be regulated in areas suffering from groundwater over-exploitation.

Groundwater Markets as an Economic Institution

A GWM is a euphemism for localised, village level informal arrangement through which owners of WEMs sell pump irrigation service to other members of the community. Water may be lifted from open or tube wells, deep or shallow wells, but sometimes also from canals, tanks, rivers and drains. It may be transported to the buyers' field either through unlined or lined field channels (as in some parts of Uttar Pradesh), through underground pipeline networks (as in many parts of Gujarat) or over-ground flexible pipes (as in parts of Tamil Nadu, Bihar and tribal areas of Rajasthan). Where landholdings are fragmented, most sellers of water are also buyers themselves; for, farmers sink wells in one or two of their largest fragments and use purchased water for irrigating others. In India and Pakistan, sellers of water are mostly sole owners of WEMs. In rare cases, WEMs are jointly owned and the groups sell surplus water to non-owners. In north Gujarat, where WEM installation costs and risks are the highest, the WEMs are almost as a rule owned by tube well companies, an indigenous form of farmer organisation that commonly sell water to non-members (Shah and Bhattacharya 1993; Kumar 2000). In Bangladesh, besides deep tube well owners who are typically large farmers, and shallow tube well and low lift pump owners who are usually small farmers, there are also landless groups owning WEMs selling water to large and small farmers in their command, either on fixed rent contract or on crop shares (Mandal 1993).[6]

Markets in groundwater were significant in many parts of India long before researchers began looking for them in the late 1980s. In the early 1990s, for instance, Pant (1993:127) reanalysed a survey he had carried out in Uttar Pradesh in 1981, and found that 86% of the households he interviewed in eastern Uttar Pradesh purchased water for irrigation and 65% purchased water in central and western Uttar Pradesh. Similarly, back in 1975, a World Bank study in Pakistan reported that about 30% of WEM owners selling a small portion of their pumpage to other farmers. More recently, Strosser and Meinzen-Dick (1994) and Meinzen-Dick (1996) found GWMs pervasive in Pakistan. A number of studies cited by them suggest that water buyers constitute 20%-40% of sample farmers and sellers to be 30%-60% of WEM owners. Similar evidence in support of the pervasive role of water markets was found by National Engineering Services Pakistan (NESPAK)[7] and Meinzen-Dick and Sullins (1994). Though somewhat different in their internal dynamic from those in western India and Pakistan, the water markets in Bangladesh have become increasingly salient in its agrarian economy (Palmer-Jones and Mandal 1987; Howes 1985; Wood and Palmer-Jones 1991; Qureshi *et al.* 2004). Up to half of the gross area irrigated by private modern WEMs in many parts of India belongs to the buyers of water. In water scarce areas, this proportion tends to be small or even zero, and in many other areas with water abundance or scarcity, as in parts of Gujarat, it may go up to 80% or more (Shah 1993; Kolavalli and Chicoine 1989). An extensive survey of 10 villages in eastern Uttar Pradesh and six villages in north Bihar (Shah *et al.* 1996b, Shah *et al.* 1996a) and six villages in Gujarat (Shah 1996a) found that while only a fraction of the land owners in a typical village owned WEMs, there was hardly any farmer who did not use purchased pump irrigation. Water markets have shrunk in many parts due to the increase in WEM ownership; yet, small farmers with fragmented landholdings continue to depend heavily on purchased groundwater irrigation (Singh *et al.* 2020).

There is an emerging evidence of rising water sale transactions throughout the world. Exchange and sale of canal water turns have been noted in some Pakistani irrigation systems, but these have been few and far between. In Tamil Nadu's system tanks, however, a large-scale sale of water amongst village communities has been reported (David Mosse, Personal Communication, 1996). Urban water markets are fast emerging in many Indian cities like Ahmedabad, Madras and Jodhpur. Typically, tube well owners in urban fringes or in surrounding villages supply tankers primarily for domestic use. Extensive sale of water for domestic use has also been reported in some parts of Africa (Whittington *et al.* 1989; Whittington *et al.* 1991; Palanisami 1994). There are large water transactions amongst corporate and municipal bodies in western California and Chile (Rosegrant and Gazmuri 1994; Meinzen-Dick and Mendonza 1996). The GWMs of South Asia are, however, by far the most extensive and well-documented. All these point out to the growing commoditisation of water, and as this trend gathers momentum, it will fundamentally change the way people and societies relate to this natural resource.

Scholars and lay observers have often approached GWMs in South Asia with suspicion – many consider this informal institution as extra-legal (which it is), inefficient and inequitable (Saleth 1994a,1994b). However, a good deal of recent research in India, Bangladesh and Pakistan has discovered positive and significant efficiency and equity impact of water markets. Four major beneficial effects of GWMs which have been extensively documented are: a) higher, seasonally balanced and more risk-free income flows from farming to non-WEM owners, who now have access to modern farming technologies, and higher induced appreciation of market value of non-WEM owners' land; b) opportunities for WEM owners to increase WEM utilisation beyond what their own land would permit, and thereby, to spread its overhead on a large command area; c) overall improvement in wages, and more and seasonally balanced employment opportunities for the landless; and (d) expansion of all the spill-over benefits that intensification of irrigation in a locale typically produces (Shah and Raju 1988). All these four benefits will be larger and more widely diffused, when water markets are more competitive.

The environmental impact of vibrant water markets is specific to the aquatic environment of the region. In waterlogged and flood-prone areas such as much of eastern Gangetic plains, the rise of GWMs enhance and intensify the drainage effect of pumping by stepping up groundwater withdrawal. On the contrary, in fragile groundwater ecologies, *ceteris paribus*, the environmental ill-effects of water markets will rise proportionately with their efficiency and equity benefits. The GWMs seldom emerge and become significant institution in areas with either too much or too little water: in the former areas, where everyone can easily access irrigation, they are redundant; and contrary-wise, in many areas of the hard rock South Indian peninsula, owners of productive wells often have a little surplus water to share after they are done.

Five Decades of South Asian Research

A growing corpus of empirical research on GWMs over the past five decades has generated evidence in support of several propositions, which have been increasingly accepted as stylised facts. Three of these are: 1) Public tube well programmes and community management of WEMs, though idealised, have achieved a limited success either in terms of efficient service provision or in containing the inequity and scale-bias inherent in private groundwater irrigation; moreover, government and co-operative irrigation organisations have tended to crumble in the face of competition from aggressive private sellers except when their internal organisation is designed for high levels of incentive compatibility;[8] 2) There is a significant skewness in the distribution of privately owned WEMs in favour of large farmers, and this skewness increases across regions as capital investment in establishing modern WEMs increases – emergence of GWMs ensures that access to groundwater irrigation is less skewed compared to WEM ownership; and, 3) GWMs are pervasive in India, Pakistan, Bangladesh and Nepal terai, and they tend to grow together with modern groundwater irrigation itself – WEM owners typically sell 40%-70% of their annual pumpage to other farmers, sellers themselves are often buyers as well, pump irrigation markets may well be the largest irrigation source in many groundwater irrigated areas of South Asia, and in canal commands, vibrant pump irrigation markets function and create substantial beneficial productivity and equity impact. Thus, from the viewpoint of securing broad-based access to irrigation, GWMs could well be viewed as a contender alongside other public programmes to promote small holder irrigation, such as public tube well programmes, community irrigation and subsidies to small farmers for boring and buying pumpsets.

Evidence on aforementioned (2) and (3) has been recorded during the past decades by numerous researchers in India, Pakistan and Bangladesh.[9] In general, their conclusions are: (a) water markets significantly raise average crop yields and cropping intensities on water buyers' fields compared to non-irrigated fields; (b) crop yields and cropping intensities on water buyers' fields are typically lower than on well-owners' fields, although many studies have found the opposite trend in some situations (Shah and Raju 1988; Satya Sai 1987; Shah *et al.* 1996a; Shah 1996a; Razzaq *et al.* 2019; Manjunatha *et al.* 2016)); and, (c) labour use on fields irrigated with purchased water is significantly greater, and more evenly spread through the year compared to non-irrigated fields. Once in a while, however, a study comes up to show deviation from this general trend. For example, Meinzen-Dick and Sullin's (1996) Pakistan study showed no impact of water markets on cropping intensities of buyers, although the yield impact was clear. Similarly, Strosser and Kuper (1994) found no significant differences in yield between non-users of tube well water, buyers and WEM owners, probably because the non-users of tube well water in Pakistan canal commands are those with the best access to canal water. Manjunatha *et al.* (2016) found the highest 'technical, allocative and economic inefficiency in the irrigated production due to overuse of inputs' among non-participants in water market, followed by water sellers and the water buyers who were the most efficient users not only of water but also of all productive factors.

Water Market Performance and Impact: Degree of Development

Studies of GWMs have focussed on three aspects: the degree of their development as an economic institution, economic efficiency of water market transactions, and their overall economic impact which are closely linked to the first two. The GWMs across areas vary in terms of their depth and breadth. Breadth is indicated by the proportion of the farming community participating in water trade as buyers or sellers or both, and depth is suggested by the quantitative significance of water transactions in the economies of individual farm households of a community. Water markets are developed where they have attained high levels of depth as well as breadth. In such a community, (a) since each seller and buyer has many alternatives in water trade, the central tendency is towards a uniform set of water transactions,[10] (b) transactions are commonly monetised and standardised, (c) the proportion of WEM pumpage sold rises to 40% to 90%, and (d) purchased groundwater is extensively used by all, including many WEM owners. In contrast, in underdeveloped water markets, (a) conditions are closer to autarky, (b) the proportion of the WEM pumpage sold tends to be small, (c) the extent of use of purchased water by non-WEM owners is small, and (d) transactions are mostly in kind, leading to inter-locking of water, credit, labour and even output markets. Degree of development of water markets is intimately linked to, but is not synonymous with, their efficiency as an economic institution. While underdeveloped markets are, as a rule, inefficient, one often finds developed GWMs are inefficient too (Shah 1993, 2009).

The monopoly power, that is, the capacity of the seller to extract monopoly rents, in water markets tends to be personalised because of the unique locational or other advantage of a WEM owner, as well as generalised due to the downward sloping demand curve for purchased pump irrigation. In developed water markets, personalised monopoly power declines or disappears as the prices charged by different sellers show narrow variations that can be attributed to factors like pump capacity differences. On the contrary, in underdeveloped water markets, price variations are large and usually reflect variations in individual seller's personalised monopoly power.

Analysing the process and determinants of development of water markets is important for several reasons. A higher degree of development leads to a reduction in the scope for personalised monopoly power and more socio-economic impact, and they are useful as indirect instruments of public policy (Acharyya *et al.* 2018). *Apriori*, the availability of water resources, scale and quality of adoption of irrigated farming technologies, progress of rural electrification, quality of power supply and the pricing of power supplied to pumpers, extent of land fragmentation, and the pace of overall economic development of the area are all among the factors that could influence the pace of deepening and broadening of water markets in a region (Shah 1993).

Until the 1980s, evidence suggest that the scale of water market activity tends to be small in areas of acute groundwater scarcity or of overall water abundance. However, the recent decades have shown a runaway expansion in GWMs in groundwater-rich eastern Ganga basin as well as in canal commands area. This is presumably because the on-demand availability of reliable and timely groundwater irrigation service through GWMs is especially valuable in value-added farming such as dry season fruit and vegetable farming, as well as boro rice cultivation in West Bengal and Bangladesh. Since GWMs are essentially lease markets for WEMs, increase in the density of

WEMs – measured, for example, as installed horse power (hp) for every 100 ha of net sown area – increases the depth and breadth, but beyond a threshold level, it leads to shrinking of water markets as the community gets saturated with WEMs. For a while, the propagation of low-cost pumping equipment, such as the treadle pumps popularised by the NGOs in low-lift areas of Bangladesh and eastern India, enabled poor water buyers to substitute their family labour for purchased diesel pump irrigation service from GWMs. However, once Bangladesh liberalised imports of used Chinese pumps during the 1980s, GWM's crowded out treadle pumps altogether. In hard rock areas with low well yields, WEM owners are reluctant to share water with others. However, even here, water markets tend to develop in some pockets, where modern crop production technologies are widely practiced and the full economic potential of irrigated farming recognised.

The east Indian states of Orissa, Bihar and West Bengal have large groundwater reserves, but were slow to develop GWMs compared to western parts (Mukherji 2004). The constraints were from supply as well as demand sides. The pace and quality of rural electrification in the east has been extremely slow. The sluggish spread of high yield varieties (HYV) – fertiliser technology and dominance of rainfed farming have meant less opportunities to sell water. Feudal social structures and taboo on water selling have also played a role. Things have been changing rapidly, however. After a long frustrating wait for good quality electricity supply, farmers in these regions have taken to diesel pumpsets in a large way, and booming markets in diesel pump irrigation have sharply raised the spread of irrigated agriculture (Shah *et al.* 1996a; Shah *et al.* 1996b).[11] In the winter of 1996, Shah and his colleagues could locate numerous farmers without their own pumps in eastern Uttar Pradesh and north Bihar, but hardly a few who did not irrigate in rabi season with purchased water. Water rates were Rs 25/hour ($ 0.71/hour) for the output of 5 hp diesel sets for nearby farms and Rs 35/hour ($1/hour) for distant farms, if they supply water through 500'-1,500' of rubber pipes which diesel pump owners have begun to own. In north Bihar, rubber pipes are commonly on hire too at a rate of Rs 1/100 feet per hour. Some diesel pump owners sent water as far as 1.5-2 km using rubber pipes leased from several parties, and in such cases, water buyer had to pay the rental for the pump and the pipes.[12] In the late 2010s, GWMs in West Bengal (Acharyya *et al.* 2018; Fujita *et al.* 2003), Bihar (Singh and Arya nd; Durga 2020; Kishore 2004; Kishore *et al.* 2014), Uttar Pradesh (Mukherji, Pant 2004; Pant 2005), coastal Orissa, Bangladesh (Mottaleb *et al.* 2019; Fujita 2005) and Nepal terai (Urfels *et al.* 2019; ADB 2012) are as vibrant, deep and broad as anywhere else in the sub-continent. Mottaleb *et al.* (2019) have recently shown in Bangladesh that (a) GWMs contributed to achieve Bangladesh's food security, (b) a variety of irrigation payment methods have emerged with expansion of irrigation, (c) social capital, personal relationships and risks shape irrigation payment methods, (d) competition among pump owners ensures a socially desirable payment method, and (e) economic and agronomic risks influence crop sharing payment method.

The efficiency promoting role of GWMs is increasingly evident in the rising importance of mobile rubber pipes in groundwater irrigation. In Bihar, Shah and Ballabh (1995) found the seller renting out both the pumping plant as well as the conveyance system (that is, rubber pipes) to enlarge his rent. Unlike this, in some other regions like Panchmahal district of Gujarat, diesel engine owners are unable to invest in rubber pipes, and traders and money lenders in small towns and large villages have in recent years added hire of rubber pipes to their portfolio of services – water buyers from surrounding villages reach them in the morning to hire rubber pipes at a rate of Rs. 10/100 feet per day, carry them on bullock carts and bring them back by 9.00 am next morning, failure of which would attract an extra day's rental. Water buyers take so much trouble to get rubber pipes because the WEM owners with 5 hp diesel pump sets in this region charge a high Rs 45-55/hour of pumping; and if the field being irrigated is at some distance from the well-head, use of rubber pipes to convey water can significantly reduce the hours of pumping needed for watering (Shah 1996a).

A good description of early stages of water market development is offered by Lall and Pachauri (1994) based on their study of three villages in the Bundelkhand region in Uttar Pradesh. In this hard rock area with limited groundwater potential, the Green Revolution had preceded the tube well revolution, and traditional irrigation technologies such as *rahat* mounted on shallow dug wells were used to irrigate HYV crops. Lall and Pachauri found all manners of water transactions, be it cash payment, kind payment, and crop share, and within each, they found a variety of prices (or terms) at which water was supplied – a few electric WEMs charged Rs 10-20/hour depending upon the competition each faced. However, the rapidly increasing diesel engine population had squeezed the economic rents they commanded. Earlier, the running cost of a pumpset was $1/4^{th}$ or $1/5^{th}$ of the hourly rent, and this gradually fell to 1/3rd of the rent charged. With the number of pumpsets increasing in the villages, the bargaining power of the sellers got reduced, and consequently, the gap between rentals charged and incremental costs got smaller (Lall and Pachauri, 1994).

In contrast to this, well-developed GWMs which have existed in central Gujarat for 70-80 years had emerged into a sophisticated economic institution. These differ from elsewhere in South Asia in that (a) farmers invest in modern WEMs not so much to meet own irrigation needs but for selling water that has become a specialised subsidiary occupation, and (b) substantial private investment made in underground pipeline networks generated a high degree of competition amongst monopolistic sellers. The evolution of such irrigation grids is by no means uniform in different parts of Gujarat. It is likely that areas which are agriculturally advanced have better developed grids, and once one or two WEM owners begin using pipeline networks, others seem to follow suit.[13] If this is the case, then subsidising such investment for a few WEM owners in a new area to start with may have large multiplier effects especially in water scarce (WS) areas. In addition to making the water markets more competitive, investment in underground pipelines would also increase the efficiency in water and energy use. In general, water markets in western and north western regions have developed into pure economic institutions, where little else seems to matter than economic considerations.

In developed water markets like Gujarat's, the prevalence of generalised monopoly power of sellers readily translates into economic rent, but in less developed water markets, personalised monopoly power of sellers gets enmeshed with social and political stratification. Wood's exploratory study (Wood 1995) of water markets in Pachera, a north Bihar village, describes a complex institution dominated by a cartel of 25 diesel pumpset owners who serviced over 100 bamboo-bores. Buyers may either have a bore or a pumpset, or none. An intricate web of kinship ties and non-economic elements influenced the terms of each transaction around a cartel fixed price. People in Pachera were far more reluctant to talk about water selling than their involvement in corruption or bribes. 'The whole idea of selling surplus capacity, of water selling, was perceived to be immoral, to be admitted in extremis'. Water sale was not a pure economic transaction; it was seen "as a favour to less capitalised families, a sharing of good fortune. a bonus income not sought after.. or an opportunity for leverage over another family in order to secure more land or labour at periods of peak demand"

(Wood 1995: 83). The mobile diesel pumpsets keep moving from one bore to another serving "pump-set owners first, non-competitive kin second, favoured clients third, and then a non-random group of non-intimate others where price is not determined by price-elasticity but other 'leverage' or power considerations, socially and culturally embedded, variably specific to different families" (Wood 1995: 85). Each pumpset had its own territory defined by kinship, caste and dependent client families of other *tola*. A pumpset owner could not merely extend his territory in response to elasticity of demand because of the cartel agreement on a fixed higher rate of Rs 10/hour 'so that a desperate, weakly networked, small farmer cannot secure access by offering a higher price'. The dealings of a seller are shaped by 'concentric circles of moral proximity. The greater the moral distance from the provider, the more instrumental the transaction'.

In many water scarce areas, the dynamic of water markets generates a complex political economy of its own, if demand for irrigation is strong. In his village case studies in Tamil Nadu, Janakarajan found a strong evidence of monopolistic skimming of irrigation surplus by sellers.[14] Janakarajan (1994) also found an evidence on inter-locking of water with labour and credit markets creating water lords with formidable concentration of local economic power in the hard rock and water scarce south Indian peninsula. In a study of 13 villages in the Vaigai basin of Tamil Nadu, where competitive pumping has permanently lowered water tables, he found water prices varying greatly in response to changes in demand, as well as supply conditions within and across villages. Prices were low for low yielding wells, for electric WEMs and for water conveyed in open channels. They were high for wells with high discharge rate, for those using diesel engines and for water conveyed through PVC or concrete underground pipelines.

Output sharing contracts are common in water markets, and many think they work against water buyers. However, in a study of water markets in Madhya Pradesh using output sharing contracts and bargaining relationships between sellers and buyers, Kajisa and Sskurai (2005) found no significant inefficiency on farms managed by output sharing buyers, presumably because optimal input intensities were achieved through effective monitoring and contract adherence mechanisms embedded in long-term and intensive personal relationships between sellers and buyers. As for equity, the finding is that, while output sharing buyers pay higher water prices, the rate of premium is merely five percentage points higher than the informal interest rate that they would have had to carry under other types of groundwater contracts. The results also show that buyers who have access to alternative water sellers pay lower water prices. In rural areas with imperfection of credit and contingent markets, informal groundwater markets work fairly well in agrarian communities when monitoring and contract adherence mechanisms are embedded and a sufficient number of potential sellers are available (Kajisa and Skurai 2005).

The prevalence of exchange of water for crop share is an enigma in the water market research. As in the tenancy in land, the most important question is: why does it persist? What factors explain the variations in the crop share claimed by water sellers in different regions? In general, in early stages of water market development, several cash sale and water-based tenancy contracts predominate water trade.[15] In Bangladesh, three types of contracts have been popular: (a) in co-operative or government tube wells, water is charged per acre at full cost estimated at the start of the season, (b) in the second system, a low flat charge per acre is collected at the beginning, and each buyer is required to bring his fuel at the time of irrigation, and (c) the last method is based on crop share which is commonly 25% but varies according to water market conditions. Each contract produces its own dynamic: in (a), the farmer tries to extract as much irrigation as possible; under (b) and (c), there is an element of marginal cost pricing; and, under (c), which is preferred by the buyer, the seller has greater stake in providing good quality irrigation service, he shares the risks, and he finances irrigation right up to the harvest which he does not under buyer-brings-the-fuel contract (Morton 1989). As the water transactions increase, apparently, the multiplicity of kind contracts gives way to one or two standard and widely used contracts, and outright cash payment for water gains precedence over crop sharing contracts. In a recent study of Bangladesh's water markets, Mottaleb *et al.* (2019) noted, "Greater competition among pump owners increases the likelihood of pay-per-hour services and reduces the likelihood of crop harvest sharing arrangements" (Mottaleb *et al.* 2019: 242).

Depending upon the intensity of competition and the economics of WEMs, the share claimed by water sellers in output may change substantially across space and time. In many parts of India, for example, a one third crop share for water is quite common. In Bangladesh, the share of water dropped from 50% first in the early 1980s to 33% and further to 20%-25% in some areas, as competition in local water markets intensified (Palmer-Jones and Mandal 1987). In Gujarat, in contrast, water sellers claimed 50% and in some cases even up to 66% of the crop share in the mid-1980s (Asopa and Dholakia 1983; Shah 1985). However, the crop share-based water selling has been replaced by cash sales in much of Gujarat, except in north Gujarat.

When water is sold for cash, it may be priced on the basis of acres irrigated of a particular crop, or on the basis of hours of pumping. Price per acre of a crop is more common in some southern regions, especially with electrified WEMs, although price per watering too is often encountered. In Gujarat, price per hour of pumping is more widely practiced – owners of electrified WEMs often charge per unit (kwh) of actual power used by taking meter readings. In case of diesel WEMs, either a full price per hour may be charged in which case the seller procures diesel or, as in many parts of southern India and Bangladesh, the seller may just charge a fixed sum per acre as rent for the use of the WEM. The buyer has to arrange for diesel/oil. The variations in the effective price of water are large: at the one extreme, there are studies which indicate water selling at a price lower than operation costs (Shah and Raju 1988; Strosser and Kuper 1994), and on the other extreme, in tribal areas of Panchmahal district in Gujarat, water pumped by a 5 hp diesel pump is commonly sold at Rs 55/hour when less than a hundred miles away, the owner of a similar capacity diesel pump sells at Rs 15/hour (Shah 1996a).

Because WEM owners have an upper hand in the water sale transactions in most conditions, the terms at which water gets sold has an important equity dimension (Yashodha 2020). For making a rabi or summer crop possible on his land, a buyer is often willing to offer substantial proportion of his income net of costs, and sellers can extract sizeable economic rent.[16] On the fringe of the desert of Kuchchh region in Gujarat, over two third of the wells in a typical village have brackish water, and the lucky owners of wells with fresh water can name the share they want of the buyers' crop they will irrigate (Vasram Mehamadavadi, Personal communication in 1996). In Panchmahal's tribal belt in north west Gujarat, a diesel engine with a productive well is treated by local people as equivalent to owning five acres of land (Shah 1996a). In Bangladesh, where water supply on share cropping basis has been a popular contract at early stages, researchers were concerned that share croppers were suffering and becoming poorer, but massive expansion of pumping equipment made competition amongst sellers so intense that crop shares charged for irrigation in many areas fell drastically (Mandal 1989). Abundant water near to the ground surface and the policy of massive subsidy and credit support to deep tube wells, shallow tube wells and low lift pumps of farmers and landless irrigation groups have facilitated the rise of GWMs to the center-stage of Bangladesh's agriculture.

Performance of Water Markets: Economic Efficiency

Two aspects of the debate on economic efficiency need to be distinguished: one, the role of water markets in promoting efficient resource allocation, and two, the efficiency of water markets themselves as an economic institution. An important point in the South Asian debate has been whether resource allocation efficiency can be achieved along with water market efficiency, and if not, what might be the second-best solution.

Groundwater irrigation involves three scarce resources with alternative costs: capital in establishing WEMs or pump capital, energy to operate them, and water whose scarcity value (hence, the marginal social cost) varies across space and time. At the society level, efficiency in the groundwater economy implies efficient allocation of all these resources. The GWMs help the society to economise on pump capital by promoting its efficient use. In the absence of water markets, the pump capital stock needed by a community of small-holders would be much larger and the average utilisation of WEMs much lower. Policies that discourage water selling result in excessive and under-utilised pump capital. As Banerjee *et al.* (2012) claimed, "the observed water trades result in efficient water allocation across farms" (Banerji *et al.* 2012:228).

Efficiency in energy use in pumping can be secured through setting energy prices at their long run marginal cost. However, since water is treated by its users as a free good even where it is scarce, there are inherent problems in securing efficiency in water use. In case of groundwater, however, energy prices as well as WEM capital costs can be used as surrogates of water production costs. In areas under severe water stress, the social value of water may be higher than marginal social cost of energy, and so, marginal cost pricing of energy may not create adequate disincentives for groundwater use. Here, taxes on WEM costs can reduce WEM density, and tax on energy used for pumping can reduce average pumpage of the WEMs. In waterlogged areas, in contrast, subsidies on WEM costs and energy used in pumping can produce opposite effect and maximise the positive externality in the form of vertical drainage. Overall, efficient resource allocation in the groundwater economy can be secured when the resource with the highest marginal social opportunity cost in each situation is efficiently used.[17]

From the farmer's viewpoint, however, the groundwater market is efficient, if the price at which irrigation service is delivered approximates the long run average cost to the seller of supplying it. Increasing water market efficiency is critical for cutting personalised as well as generalised monopoly power and for maximising overall economic benefits from groundwater economy. Buyers operating in inefficient water markets benefit by switching from purely rainfed to irrigated farming, but suffer adverse productivity and distributive effects. First, high water prices force them to economise on water use more than WEM owners do and to use irrigation too sparingly and for productive purposes, and consequently, their transition from traditional farming to modern HYV technology is either blocked or impeded, which may represent a wasted opportunity in category [a] and [b] areas, but may be necessary, if inequitable, in category [c] and [d] areas. Second, water sellers in inefficient markets commonly appropriate a lion's share in the irrigation surplus that purchased pump irrigation generates on buyers' lands, thus, creating substantial skewness in the distribution of a community's irrigation surplus in favour of WEM owners and against water buyers. Field research in South Asia is unequivocal in that monopolistic water markets permit sizeable extraction of monopoly rents by sellers, and therefore, produce adverse distributive impact; however, the picture on the productivity impact is less clear. In water scarce areas, water buyers tend to use more water-economical-cropping-patterns and intensities compared to WEM owners (Shah 1996a; Shah and Raju 1988). In water abundant areas, the differences between water buyers and WEM owners are often not significant because of the relatively price inelastic derived demand for pump irrigation (Shah *et al.* 1996a; Shah *et al.* 1996b).

The productivity as well as distributive benefits of efficient water markets can be maximised by making water markets competitive by curtailing generalised monopoly power enjoyed by sellers. Several factors affect the degree of monopoly power enjoyed by water sellers in a given locale. They include high and stable rainfall, abundant groundwater close to the ground, flat topography, cropping patterns needing relatively less irrigation, low cost of WEM installation, absence of siting and licensing norms, high WEM density, stable and dependable electricity and diesel supply, access to alternative irrigation sources such as canals, tanks or public tube wells, and tradition of lined channels or underground pipelines to convey water. Some of them are not under the control of policy makers. A few others such as increasing the density of WEMs, creating alternative irrigation sources and laying underground pipelines through buyers' field are not easy to implement quickly, and each of them may cost a great deal of resources. Finally, a recent evidence shows that even very high levels of WEM density eliminate only personalised monopoly power, but has limited effect on generalised monopoly power (Shah *et al.* 1996a; Shah *et al.* 1996b). In eastern Uttar Pradesh and Bihar, one can find pockets where exceedingly high WEM density has forced water markets to shrink rather than become more efficient (ibid.).

One line of arguments for quickly increasing the efficiency and equity of water markets has focussed on imaginative use of energy pricing and supply policies as a lever to influence the behaviour of millions of pumpers, and thereby, of the structure, conduct and performance of groundwater market. Two energy sources extensively used in modern WEMs are diesel and electric power. Since it is not feasible to sell diesel at different prices to pumpers and other users, it offers a little scope for selective intervention in the groundwater economy. Power utilities charge differential prices to different segments of consumers of electricity. The differential pricing works in electricity supply because of a limited scope to transfer power purchased for one use to other uses, and so, electricity pricing offers some scope for selective intervention in the groundwater economy.

Early Indian studies found systematic variations in generalised monopoly power of sellers across states (Mukherji 2009). They also found that diesel WEM (dWEM) owners everywhere and electric WEM (eWEM) owners in states that charged for electricity on metered consumption basis or on pro rata basis tend to extract substantially higher monopoly rents, in comparison to eWEMs in Indian states where electricity was charged on a flat rate (FR) linked to the horsepower rating of the eWEM because of its administrative and logistical convenience. Repeated confrontation with such evidence led to the thesis that price formation in water markets can be explained by a simple, almost of-the-textbook, model based on the neo-classical imperfect competition theory (Shah 1993).[18] It was argued that a water seller is a natural oligopolist. Because of locational and topographical factors, water sellers in different communities enjoy varying degrees of monopoly power over their buyers. The monopoly power of a representative group of sellers increases in arid areas in years of draughts, in areas with low WEM density and in the absence of alternative irrigation sources; and vice versa. Recent field experiments similarly suggest higher bargaining power of sellers over buyers (Yashodha 2020). Using standard neo-classical economics, it was further proposed that water price charged by WEM owners in a community is best predicted by the marginal pumping cost facing them times [e/e-1], where e is the price elasticity of demand facing water sellers. In areas subject to FR under which marginal pumping costs become very nearly zero, eWEM owners have strong incentives to adopt a low-margin-high-volume business policy. And, dWEM owners everywhere and eWEM owners facing pro rata tariff (PR) are impelled towards a high-margin-low-volume business strategy (Shah 1993). Higher pro rata electricity price than the marginal cost of supplying it can, thus, be valuable as a tool for regulating groundwater use by WEM owners and water buyers. Similarly, in water abundant areas, a moderately high FR can be used to stimulate water markets, broaden access to groundwater through low-cost pump irrigation service, maximise the efficiency of pump capital, and strengthen the positive drainage externality. In the first case, efficiency can be achieved in water and power use, whereas in the second, water use and pump capital use may be more efficient than power use.

A family of auxiliary hypotheses about the micro analytics of GWMs have received some empirical supports from recent studies in Uttar Pradesh, north Bihar and Gujarat (Shah *et al.* 1996a; Shah *et al.* 1996b; Shah 1996a). These studies have yielded *ceteris paribus* useful policy implications: (1) where FR paying electric WEMs compete among themselves in an area, water price tends to get pushed to the minimum, especially if density of electric WEMs is high; (2) where FR paying eWEMs dominate the water market that also has a minority of dWEMs as sellers, the latter are obliged to accept the former's price leadership and whittle their monopoly rents down to the minimum; (3) when a minority of FR paying eWEMs operate in a water market dominated by dWEMs, the former find it advantageous to accept the price leadership of dWEMs and end up charging significantly higher prices than they would in markets dominated by FR paying eWEMs; (4) where PR-paying eWEMs compete with dWEMs, the overall rent extraction by water sellers is at its peak; (5) eWEMs paying high FR tend to be more aggressive water sellers compared to eWEMs paying zero or very low FR, thus, water markets are likely to be more vibrant, and water prices remain low (if not proportionately higher) when eWEMs are subjected to high FR than if they pay zero or low FR; (6) water prices charged by FR paying eWEM owners tend to increase sluggishly in response to increases in FR, but when subjected to an increase in diesel price or PR electricity tariff, dWEM and PR paying eWEM owners are likely to raise their water prices more than proportionately, in fact, by a multiple which reflects the generalised monopoly power [e/e-1] enjoyed by water sellers in a given area; (7) how high a FR would be optimal for producing vibrant and equitable water markets would depend upon the quality of the power supply environment – if electricity supply to agriculture is limited and of poor quality, high FR would oblige eWEM owners to exit en masse and, where possible, switch to dWEMs[19], and high FR accompanied by high quality of power supply environment[20] would produce vibrant and equitable GWMs[21] which over time would get dominated by eWEMs that will edge dWEMs out of the market, and when high FR is not accompanied by a high quality of power supply environment in a region where dWEMs are technically infeasible, groundwater irrigation at the level of the region will shrink, and in the absence of alternative irrigation sources, it would hit the agrarian economy hard; and finally, (8) given time, under zero or low FR, there would be powerful incentives for small holders to aquifer eWEMs, that is, growing self-sufficiency in pumping capacity would lead to excessive and under-utilised pump capital, and shrinking of GWMs and decline in their salience in the village agrarian economy.

Part III

Conclusions and Policy Implications

Indirect Instruments for Managing Groundwater Markets

Early water market research (Shah 1993) classified areas into four categories: [a] those facing *excess of groundwater* such as the waterlogged areas of canal commands and flood prone regions like eastern Uttar Pradesh, north Bihar, and parts of Bangladesh; [b] areas with *abundant and under-developed* replenishable groundwater resource; [c] areas with *limited and/or fully developed* groundwater resources; and [d] areas already facing problems of severe *depletion, over-draft and/or saline ingress*. As Mukherji (2020) has recently highlighted, governing groundwater for productivity, equity and sustainability demands adherence to energy-water nexus approach. A constant refrain of the water market research was the need

Box 1
Impact of Electricity Pricing and Supply Policies
on the Groundwater Economy

Electricity Pricing Policies → Electricity Supply Conditions ↓	Full cost flat electricity tariff and no subsidies on WEM capital cost (as in Gujarat)	Consumption-linked energy pricing with subsidy on WEM capital cost (as with diesel WEMs in Uttar Pradesh, Bihar, Bangladesh)
Impact on water markets under favourable power supply environment	[I] low density of WEMs; vibrant water markets; high WEM capacity utilisation; low efficiency of water and power use; wide diffusion of access to irrigation through water markets	[II] high WEM density; water markets have low breadth and depth, and may give way to autarky; WEM utilisation very low; water and power use efficiency may be higher; pump capital may be inefficiently used.
Impact on water markets under unfavourable power supply environment	[III] where water table is high, farmers switch to diesel WEMs wholesale; where diesel pumps are infeasible, ground pumps are infeasible, groundwater economy may decline.	[IV] where water table is high, farmers switch to diesel WEMs wholesale; where diesel pumps are infeasible, groundwater economy may decline.

to evolve new policy tools to respond to the challenge facing each of these categories. Studies of GWMs highlighted the potential to devise such tools. They showed that the nature and scale of the overall effects of GWMs in a region depend upon (a) the extent to which water markets have developed, (b) the efficiency of market transactions and of the various resources used by these transactions, and (c) the fit between the groundwater endowment of a region and the system of appropriation implied by water markets. An important argument has been that, if carefully designed and implemented, electricity pricing and supply policies and tax/subsidy on WEM capital cost can be used to influence, especially in conjunction with other measures, all these three factors at once as outlined in Box 1.

Critical in this argument is the strategic use of FR, which militates against the marginal cost pricing principle and creates the threat of inefficient power use (Mukherji 2008a; Shah and Chowdhury 2017).[22] The experience of using FR in India has been a travesty of this argument, as power subsidy was used as a mechanism of resource transfer, and its purpose of enabling small holders to access low-cost irrigation has been countermanded by the state electricity boards, which have allowed the quality of rural power supply and distribution infrastructure to deteriorate to a level that the actual power used by pumpers is low enough for the FR to more than cover the full cost of power supply to them. As a consequence, leave alone subsidised supply, studies in Uttar Pradesh, Haryana, Bihar and Gujarat indicated that the effective average cost of power paid by farmers in these states is higher than even commercial and industrial users (Shah 1995, Shah *et al.* 1996a; Shah *et al.* 1996b, Palanisami 1994; Mukherji 2008b). Faced with this high real cost for power supply of poor quality, farmers throughout eastern Uttar Pradesh and north Bihar switched wholesale to dWEMs (lower panel of Box 1). Thus misused, the overall impact of the FR policy was de-electrification of entire region's countryside (Mukherji 2004).

If used strategically, however, FR can be an important element of the policy toolkit that could secure the second-best outcome, as alluded earlier. In principle, a community can create optimal stock of pump capital by using appropriate taxes/subsidies on the price of the WEM. A groundwater management regime can be organised as in central Gujarat, where a small number, typically a dozen or so, of high capacity tube wells irrigate 1,500 acres or more of net sown area using a complex network of criss-crossing underground pipelines. The same size of area may be irrigated in Bangladesh, north Bihar or eastern Uttar Pradesh by 300-500 small capacity WEMs conveying water in open field channels. Policies that tax WEMs and subsidise their operating cost and investment in distribution system encourage the first type, and those that subsidise WEMs like the free boring scheme of Uttar Pradesh and Bihar governments encourage the second type of arrangement.

The FR cause high fixed costs and low variable costs of operating an electric WEM resulting in high operating leverage (that is, contribution/operating profit). Removing subsidies on WEM capital costs reinforces this effect. High operating leverage persuade farmers to be cautious about investing in a WEM, but once s/he has invested, it impels him to maximise its utilisation by selling water. The FR can, thus, be used to stimulate GWMs, reduce pump density, lower water prices and enhance total groundwater draft in an area. In contrast, PR, especially when accompanied by capital cost subsidies on WEMs, leads to low fixed costs and high incremental pumping costs producing low operating leverage. It would lead to high WEM density, high water prices, and eventually, autarky. High FR combined with high consumption linked charge in a scheme of two-part tariff can help to reduce WEM density and average pumpage per WEM. This logic can help to evolve new policy tools for managing the groundwater economy for efficiency, equity and sustainability.

In category [a] areas, rather than spending public resources on augmentation of tube wells[23] and expensive drainage systems, it might make sense to subsidise groundwater irrigation by stimulating highly developed and efficient pump irrigation markets. The FR backed by abundant and reliable power supply is best suited. In addition, providing direct subsidy on pumping groundwater would support other public initiatives to tackle waterlogging and flood-proneness. Similarly, where farmers use a large amount of groundwater in the treatment of usar lands and for leaching salts, some subsidisation may help to internalise the externalities of usar land reclamation. In [b] type areas too, high FR with adequate power supply would make sound economic and environmental sense, especially with close monitoring of the changes occurring in the groundwater hydrology (Mukherji 2007; Mukherji 2008a). Free or subsidised electricity that followed FR for tube well irrigation has grave economy-wide implications in states like Punjab (Smith *et al.* 2015). However, strategically used FR need not necessarily involve subsidies to agricultural power supply, but even if it does, its overall environmental, efficiency and equity benefits may far exceed the cost of subsidy.[24]

In [d] type areas, environmental costs are so high that any policy that can contain groundwater draft, no matter what the efficiency and equity costs, may be indicated. High consumption linked power tariff accompanied by high FR to discourage investment in new WEMs can make eWEMs uneconomic, especially if there is also rationing of power supply for pumping. In many [c] type areas, groundwater irrigation can go on, but the overall rate of draft must be limited to long-term average recharge. In this category, encompassing a large part of peninsular hard rock India, appropriate power pricing and supply policies need to be deployed in conjunction with other instruments. In category [c] and [d] areas, the reverse logic operates, but an important equity issue here is of distributing the cost of achieving sustainable groundwater use between WEM owners and water buyers. The total groundwater extraction can be controlled either by setting energy prices at a level that reflects the scarcity value of water or by rationing power supply to limit extraction to a sustainable level, or to use a mix of both the options. With price rationing, pump irrigation rates will soar up forcing buyers to pay [e/e-1] times the scarcity value of water as price to WEM owners, and thus, share a greater proportion of the cost of the environmental sustainability than sellers. In the second option, controlling over draft is probably easier and, since monopoly rents can be contained by charging moderately high FR, sellers and buyers would share the costs of environmental sustainability in a more equitable manner. However, this would work only in areas where diesel WEMs are technically infeasible, as for example, in Mehsana district of north Gujarat. Elsewhere with high electricity price and/or low power supply, diesel engines will replace electric WEMs, and the policy regime recommended would break down.

Links between electricity pricing and groundwater management have been widely discussed in recent years. Because FR is commonly used to disguise subsidies on electricity, this association has in some ways prejudiced the discussion on the potential of using electricity pricing and supply policies as levers to influence the actions of millions of private pumpers. It is commonly assumed, though erroneously, that state governments will never have political courage to raise FR to logical levels,[25] and that PR will automatically lead to efficiency and conservation, besides pulling the electricity boards out of the red. The arguments have come under intense scrutiny on analytical grounds as well. Some researchers have suggested that the entire corpus of work on which this argument is founded "is based on a limited range of empirical material and a simple model of monopoly which is not robustly supported by the evidence" (Palmer-Jones 1994), and 'imperfect information is a better approach with which to understand variations in the irrigation service market structure, conduct and performance' rather than the simple neo-classical model which much existing work has used (Shah 1993). It is also suggested that power pricing and supply policies can help in regulating groundwater draft only if the demand curve for power is downward sloping and convex. But "unfortunately, this assumption is invalid for two reasons; firstly, the power demand curve has a 'kink', and secondly, farmers will switch to diesel engines if electricity tariffs are too high" (Saleth 1993). Based on field studies to examine the responsiveness of water extraction rates to energy costs in pumping, the Tata Energy Research Institute (TERI) has argued that 'it is doubtful if electricity pricing can play more than a supplementary role in sustainable use of groundwater' (TERI 1994). However, the proposition that extraction rates are insensitive to pumping costs has not been supported by many studies, including TERI's. Moench has, therefore, argued that whereas the switch to consumption based tariff will raise water use efficiency, "energy price changes alone appear unlikely to have much effect on cropping decisions and thus the overall sustainability of water use patterns" (Moench 1992: A-174).

The discussion on electricity pricing and supply policies as instruments of indirect groundwater regulation, thus, remains active but inconclusive. It continues to be of interest in part because of the plausibility as well as the empirical support in favour of the arguments underlying the policy prescription, and more importantly, because extensive research in the field has failed to generate alternative instruments to effectively deal with the groundwater economy in its full complexity. A good description of where the discussion is poised is given by Moench, who adds, "Overall, electricity price mechanisms are unlikely to have much impact if used in isolation. If used in conjunction with other measures that increase their impact on crop economics, and /or increase access to efficient technologies, they could have a much more significant impact" (Moench 1992).

Water Markets and Conjunctive Use of Surface and Groundwater

A good example of how GWMs can be integrated in a strategy of sustainable water management is provided by programmes to promote conjunctive use of ground and surface water resources. Canal commands show remarkable regularities in their spatial pattern of change in groundwater tables; they invariably display a strong tendency for water tables to build up in the core command (that is, areas near the head and along the main and branch canals) and to fall in the peripheral command (that is, areas at the tail ends of the system). In a study of these tendencies in Mahi right bank canal system in central Gujarat, Shah (1991) found that, with inexpensive canal irrigation becoming abundant and reliable, farmers in the core command took to water intensive crops, flood irrigation and filling up old wells. The large irrigation return flows combined with seepage from canal and water course rapidly raised groundwater tables in the core command, and at some places, to less than a meter. In contrast, in the peripheral command, declining groundwater tables emerged as an important issue.

Since canal water seldom reached the fringe areas of the peripheral command, wells emerged as the dominant mode of irrigation here. It was only in the middle areas between the core and the peripheral commands that some kind of a steady state hydrological equilibrium was established – that is, recharge from canal irrigation prevented water tables from falling very low and groundwater irrigation kept them from rising too close to the root zone of crops. Achieving such an equilibrium throughout the command seemed one way of ensuring sustainable management of land and water, but the way the GWMs emerged and functioned in the Mahi command worked against such an equilibrium. They were vibrant and thriving in the periphery accelerating the decline in water tables, but in the core command, WEMs themselves had fast disappeared. Reversing this pattern was the key to resolving many problems of canal systems. This tendency has since been highlighted by several researchers working on different surface systems.[26]

Conjunctive use can extend the effective command of the system and control waterlogging in the head reaches by promoting vertical drainage, and can be promoted through intensifying groundwater irrigation and discouraging surface water irrigation in the core command. However, policies followed by canal and groundwater managers, such as uniform siting and licensing norms for private WEMs throughout the command, locating state tube wells in peripheral command and operating the canal system militate against the goal of conjunctive use. Three clusters of policies that can come into focus include (a) those which can strengthen incentive for groundwater irrigation in core command and weaken them in peripheral command, (b) canal system operation policies that help achieve hydraulic equilibrium, and (c) canal design parameters.

Incentives in groundwater irrigation in core command can be strengthened by (a) lowering the cost of establishing WEMs which would increase WEM density, and (b) lowering incremental pumping costs of WEM owners that would encourage vibrant GWMs and low water prices, and thereby, strong encouragement to groundwater irrigation by WEM owners and buyers. Opposite policies in peripheral command would discourage groundwater irrigation there, and this would be facilitated by reduced canal water uptake in core command, leaving more for the peripheral command.

Complimentary canal operation policies which would promote conjunctive use are illustrated by a new policy paper developed by the government of Uttar Pradesh

(Government of Uttar Pradesh 1993). For managing the core command, it suggests that (a) in areas where water table is within five meters, canals should be routinely closed in the pre-monsoon period or even put on a 5-10 year holiday, and doing this would oblige farmers to resume pumping their wells and the emergence of GWMs will further help to lower water tables, while keeping the irrigation economy alive, (b) in core areas, not only should private tube well development be encouraged, but where possible, irrigation should be done only with a dense network of tube wells, (c) permanent reclamation of *usar* (alkaline) lands can be achieved by lowering groundwater below 10 meters by planned pumping out of groundwater which, incidentally, would also help absorb rainfall recharge, reduce the run-off and minimise river-flooding,[27] and (d) instead of weekly intervals, canal irrigation should be rotated with two weeks' interval, and in general, canal rostering should be adjusted to keep groundwater level in the 6-10 meters range.

To encourage groundwater irrigation, the policy paper suggested that (a) one canal irrigation may be given free to those using own tube wells, (b) tube well owners using canal water be charged on the basis of number of irrigations used rather than for the full year as at present, and (c) subsidies and incentives may be increased to add one more million to the present 2.6 million shallow tube wells in the state, especially in the areas where water table is 2-5 meter from surface. In peripheries, the paper suggests the irrigation department should arrange to send canal water to the tail ends and plan construction of new canals exclusively for recharge of groundwater in these areas.

Redesigning canal system components offers another avenue for promoting conjunctive use. While saving the energy costs of lifting water, canals designed as gravity flow systems lose the power to check profligate use of water by head-end users who face low incremental cost of irrigation. Waterlogging and increased soil salinity in the head reaches of many canal commands are largely a result of these tendencies. Though with some success, a design solution to this problem has been tried in Egypt, where pump irrigation markets have emerged as an important supportive institution. Until three decades ago, Egyptians followed basin irrigation that requires high canalisation around a system of crop basins formed by an intersecting network of dikes and levees – all, in turn, inter-connected by a series of canals. Under basin irrigation, all irrigated farming activity was adapted to the natural rhythm of the Nile River.

With the construction of the Aswan dam, Egypt made a slow transition to perennial irrigation with the principle of low canalisation with low canal beds (Butzer 1976). All the canals of Egypt's delta water delivery system that was built by Mohamed Ali in the early 19th century were re-dug by the government in the early 1970s lowering the water level in the canals throughout to around a meter below the ground level. 'This policy was, and is, presented as a means of preventing farmers from wasting water'. Since the only way farmers could irrigate was by lifting water using *saqia* (a cow or buffalo driven water wheel) or more recently diesel pumps, flood irrigation of fields and such other wasteful irrigation practices could be checked (Mehanna *et al.* 1984).

The design change has encouraged a dense mass of *saqia* rings '[which] are ubiquitous throughout the Delta and almost every land-owning farmer family belongs to one or more such groups' (Mehanna *et al.* 1984: 19) and "..rather than providing a means for deterioration of the *saqia* ring organisation, (the diesel pump rental market) has reinforced the *saqia* ring and made it less troublesome than before.." (Mehanna *et al.* 1984:21). The study further found that the diesel pump and its rental markets "revolutionised local irrigation in the delta system water is made available 'everywhere' but for a limited time... In times of shortages, farmers get together to rent a pump, on a cost sharing basis, to lift the water from the drains or from the main canal to the *mesca* , the long ditch in which water is delivered. The availability of diesel pumps on rental has removed the most critical source of conflicts involving water" (Mehanna *et al.* 1984:64).

The pump irrigation markets emerged because of the technical change in irrigation induced by the re-digging of canals. 'Pumps are largely meaningless to the water users groups in the gravity system in Faiyum but they expand the necessary range of farmer co-operation in middle Egypt' and along with the *saqia* ring, they were found "(a) efficient in terms of the application of water to differing field situations; (b) equitable in that it allows richer and poorer farmers to choose methods that fit their economic scales of activities; and (c) safe in that it allows alternatives and backups in an uncertain environment" (Mehanna *et al.* 1984:138). The study also noted that compared to the Delta lift system and the Ibrahimia canal system, both of which require lifting of water from *mescas*, the Faiyum gravity system was found to have a serious problem of over irrigation which led to a rise in the level of Lake Qaran (Mehanna *et al.* 1984: 93) that could flood out many *feddans* of agricultural land.

Tradable Property Rights and Water Markets

We conclude this review by exploring the common ground in South Asian, American and Australian discussions on water markets. At the outset, it is necessary to highlight certain important semantic distinctions. The South Asian GWMs we have analysed in this paper are essentially surrogate water markets for irrigation service. In markets proper, sellers sell things on which they have unattenuated rights of ownership and use. In South Asian GWMs, sellers have such unattenuated property rights only on WEMs; in principle, thus, what they sell is the services of their WEMs. Nobody knows who owns the water they are selling, which is why they can get away by selling to their neighbours often at large premia, the water which may well be theirs (Ananda and Aheeyar 2020). These surrogate markets would disappear in the absence of the need for pumping, or if everyone in a community gets a WEM. In contrast, much American and Australian discussion in the field focuses on water market proper in which sellers sell water on which they have property rights recognised by buyers, other sellers and the state. The central issue the international debate has tried to come to grips with is: how to catalyse markets for water, so that water becomes an economic good rather than the scarce but free good as at present. An emerging answer is: get property rights on water clearly defined, enforceable and tradable.

Property rights on water are highly ambiguous throughout South Asia. The public ownership of surface water is implied in statutes like the Northern India Canal and Drainage Act of 1873. However, the system of *warabandhi* in northern India and Pakistan itself implies certain private rights, *de facto*. In general, the right to use surface water not captured by the state is a riparian right attached to the ownership of land (Veeman 1978). The rights on groundwater are in some ways even less clear (Saleth 1994). What exists comes closest to the English doctrine of absolute ownership that considers the owner of the land to be the owner of all the water in the underlying aquifer, conferring on him the right to pump out the water at any time in any quantity, and for any legitimate enterprise, either on or off the overlying land (Saleth 1994). Thus, those hit by any of the externalities we described earlier have no recourse to any mechanism of redressal under this absolute ownership regime, and thus, groundwater as a common property is a misnomer in South Asia, nor is the resource subject to open access, since only owners of land and WEMs can pump out water.

Based on the Californian experience, Veeman has suggested the replacement of the current system of rights in South Asia by a system of co-relative rights in which owners of all lands that overlie a common aquifer have co-relative and co-equal rights to the reasonable beneficial use of the water in their overlying lands.[28] In case of rationing, water may be apportioned by court decree in accordance with their respective reasonable beneficial needs and in proportion to their historical use. Following Singh (1992), Saleth (1994) has similarly argued for replacing the present system of *de facto* rights by a set of clearly specified water rights under the public trust framework 'which provides for a hierarchical system of rights and duties applicable for the state, community and individuals' (Saleth 1994: v)

In comparison to the South Asian debate on water rights, the discussion on tradable property rights in American and Australian context is more pragmatic because of its focus on 'the laws, institutions, and policies that condition the success of allocating water through markets in tradable water rights' (Rosegrant and Gazmuri 1994). An important aim here is to promote greater efficiency in development, appropriation and use of water by creating incentives for improved productivity of water by endowing water with an opportunity cost, by shifting water to higher value uses and by promoting greater investment in water production and conservation (Thobani 1995). According to Thobani, "..a market system increases the value of water, so there is more incentive to clearly define water rights, to improve measurement and enforcement, and to establish an efficient mechanism to resolve conflicts" (Thobani 1995: 3).

Gazmuri and Rosegrant (1994), Rosegrant and Gazmuri (1994) and Rosegrant (1994) studied efforts to institute tradable property rights on water in California, Chile and Mexico. World Bank (1994) also offered an analysis of similar effort in Peru. Kemper (1996) analysed the establishment of an institutional arrangement based on negotiation between stakeholder groups as the precursor to full-fledged water markets in her study of water allocation and use in Curu Valley in Northeast Brazil. In all these countries, the reform began at the initiative of the government. California announced in 1982 a state-wide policy of encouraging voluntary water transfers between agencies, and this was followed by a number of laws to permit sale, lease, exchange or transfer of water. In Chile, Mexico and Peru, water sector reform was inspired partly by overall economic liberalisation and partly by budgetary pressures. The water reform began in 1973 in Chile and in the early 1990s in Mexico and Peru. Besides creating tradable water rights, a new Water Law was passed in 1992 by Mexico that initiated the turnover of irrigation systems to farmers. Unlike in California, where water trade emerged primarily in response to growing urban demand and often against stiff resistance from farmers and rural communities, in Chile and Mexico, farmers strongly supported the water rights reform.

In the Chilean water code, existing users are given fully tradable property rights to water without charge, while new or unallocated surface water rights were distributed through public auction. These rights can be traded, mortgaged or leased as long as they do not reduce the water availability to other users, and a minimum ecological water flow is ensured. The rights are recorded in a public water rights registry and invite property tax. The right to surface as well as groundwater is distinct and separate from land rights. Peru and Mexico have pretty much followed the Chilean example. Unlike in California where water rights have been specified in consumptive terms as absolute quantities, in Chile and Mexico, water rights are prescribed in terms of the proportion to the stream-flow. The return flows are made available to farmers for use, but rights over them are retained by the district.

These experiments, except in California and Northern Colorado, are significant but still in their early stages. While water trade has developed to some extent in Chile, many of the benefits claimed are based on *apriori* logic and study of transactions that are emerging. As a result, the evidence cited on the actual trade and its impact is still anecdotal. Clearly, however, the experience of these countries, which are similar in key respects to many developing countries, offer more relevant lessons to the developing world than the experience of California.

Even so, in South Asia, the enthusiasm for initiating comprehensive water rights reforms is less strong than in many Latin American countries, despite the presence of many pre-conditions identified by Rosegrant and Gazmuri (1994) as necessary to spur such reform, like overall economic liberalisation, budgetary pressures on governments from public irrigation infrastructure and growing economic value of water. The South Asian evidence also raises questions about the thesis that specification of tradable water rights will be necessary or sufficient, or necessary and sufficient for stimulating water trade and encouraging private investment in water production and efficiency. After all, GWMs in the region have flourished into a robust agrarian institution, despite the absence of any law which explicitly formulates tradable private rights on groundwater. Indeed, in many Indian states, groundwater selling has become a vibrant activity in spite of the state electricity boards' categorical injunction against it.

In contrast, in many tank systems of south India, as in traditional irrigation systems such as *phud* in western India, water rights of farmers with land in command are 'completely specified, exclusive, transferable and enforceable', as needed for the emergence of a market (Coase 1960), and often documented in great detail. They are also upheld by the local people and guarded zealously by their holders, and yet, we see little evidence of extensive trade in tank water rights, and even less of farmers investing effort and resources in maintenance and repair of their tanks. Indeed, the decline of tank systems through neglect and disrepair is a central theme in south India's natural resources history. These seem to suggest that the way rights are created on natural resources and their impact on the way people relate to each other involve more complex questions of society than mere legislation.

In following the American-Australian-Chilean example, another major issue for many countries, especially in South Asia, will be the difficulty in breaking away from the existing *de facto* property rights, and of enforcing the new system of rights when created. This is particularly important because of the vast number of small holders who will be involved in the adjudication process, and the local power structures and political economy which, for example, made the Indian land reforms infructuous. Moreover, enforcing a new structure of property rights would necessitate strong institutions of local governance which these countries lack. Bromley has referred to "the usual practice of governments that have declared in the constitution that all natural resources are the 'property' of the nation state. Having done that, governments then proceed to ignore the management and control of those natural resources. [But] you do not own what you cannot control .. and control [does not] mean simply the presence of thousands of forest guards with pistols.. [it means] the formulation and implementation of coherent and consistent management plans for forests, for fisheries, for rangelands, for groundwater.." (Bromley 1993). And it is probably the intractable problems of enforcement that have undermined legislative action in India in this field. After all, the state of Gujarat passed a Groundwater Act in the early 1970s, but it never became the law because its chief minister knew it could not be enforced. The Government of India similarly drafted a model bill in 1992 and states like Tamil Nadu, Karnataka, Rajasthan and Maharashtra too have tried – but none of them have become law. It is widely recognised that it is one thing to make a law, but it is quite another to change property rights. Following Bromley, the only way property rights can be changed is through integrating desired change in property rights in the 'formulation and implementation of coherent and consistent management plans' for the resource.

Notes

1. The 8th Five Year Plan of India doubled the country's groundwater irrigation potential by revising downward the average irrigation delta, that is, depth of water required to irrigate a hectare of land, from 0.66 ham to 0.48 ham. Scholars like Dhawan (1990) have taken strong exceptions to this change, but it is probably true that the efficiency with which lifted water is used is much higher than gravity flow water from tanks and canals. And since for a long time, the irrigation delta used was the same for all irrigation, the downward adjustment is probably in the right direction.

2. The Irrigation Commission (GOI 1972) estimated area affected by waterlogging at 4.75 m ha in 1972; the National Commission on Agriculture (1976) upped the figure to 6.0 m ha in 1976); and in the early 1980s, the Indian Ministry of Agriculture suggested the waterlogged areas to be 8.53 m ha. All these estimates included surface stagnation of canal water as well as waterlogging of lands.

3. In their study of a Pakistani irrigation system, Rinaudo *et al.* (1994) suggest that private tube wells in canal commands are the first answer to the inequity of canal irrigation systems (p:2). Some farmers install group tube wells, but these are rare, and occur in families or close kinship groups. Exchange of canal water turns does take place, but such exchange is not common; sale of turns is even less so. Most common is the sale and purchase of tube well water. Tube well water transactions serve three purposes: (a) they increase the temporal and spatial flexibility in water availability, (b) they increase the quantity of water available or help supplement unreliable canal irrigation, and (c) they help tube well owners to cover part of tube well operation cost with profit from water sales.

4. A good example is siting and licensing norms adopted by groundwater departments banks and electricity boards in India to contain well interference and excessive withdrawals from the aquifers. These determine who is denied the right to establish modern WEMs. Since these norms have been established only in the last two decades and enforced seriously only recently, and do not affect existing modern WEM owners, they impose a 'virtual' allocation of ownership rights on groundwater that favours early exploiters and penalises late comers, who often happen to be the resource poor. Moreover, while siting norms seek to protect an existing modern WEM from another modern WEM, they do not provide any protection to existing traditional WEM owners from new modern WEMs, which have often wiped the former out of existence (Shah 1993:9-14). Spacing and licensing norms have proved difficult to enforce through the regular policing system (Moench 1994b; Dhawan 1989); therefore, in most Indian states, credit support by public sector banks and the allocation of electricity connections are made contingent upon compliance with these norms. These have worked in a regressive manner. Those who are able to self-finance WEM investment and/or use diesel engines (or of course, bribe their way to an electricity connection) thus remain unaffected by the norms.

5. In Uttar Pradesh, fierce competition from private water sellers has been instrumental in lowering public tube well performance (Pant 1993; Kolavali and Shah 1993). In NGO sponsored community or group tube wells, learning to adapt to the water market proved critical to success. In the Deoria and Vishali areas, co-operation amongst joint owners of community tube wells gradually broke down due to competitive assaults from private water sellers (Ballabh 1989; Pant 1993). In contrast, in a study of public tube well turnover to farmer groups in Mehsana district in Gujarat, Dinesh Kumar (nd) found that group members soon learnt to adapt to water markets and made their co-operatives successful by aggressively out-selling competitors.

6. A study of a Pakistani system by Rinaudo *et al.* (1994) classified a sample of 278 farms in eight water courses of the Fordwa Branch Irrigation System. Groups having large land owners with mechanised farms were the least active as buyers but were major sellers of groundwater. In contrast, ten-

ant cultivators who grew wheat and cotton for market were hyper-active as water buyers. Subsistence farmers were more active as buyers than as sellers, particularly when they practiced intensive cultivation.

7. Cited in Rinaudo (1994).

8. See, for instance, Asopa and Dholakia (1983) on how public tube wells in Gujarat caved in before growing competition from private water sellers during the 1970s, and Kolavalli and Shah (1993) on how the same story was repeated in Uttar Pradesh during the 1980s; see Pant (1993) and Ballabh (1989) for insightful documentation of how co-operatively managed tube wells succeeded for long, but began to crumble as soon as aggressive private water sellers began to compete and win over their clientele through better service; see Ahmed (1993) on competition between landless group tube wells and private water sellers in Bangladesh; and finally, see Kumar (1995) and Shah and Bhattacharya (1993) for the story of north Gujarat's tube well companies many of which have survived for half a century because of the incentive compatible design of their internal organisation, and Mehanna *et al.* (1984) for similarly designed lift irrigation organisations in Egypt.

9. See Shah (1985, 1986), Shah and Raju (1987) and Shah (1996) for Midnapur district in West Bengal, West Godavari and Karimnagar districts in Andhra Pradesh, and Panchmahal, Kheda, Sabarkantha and Mehsana districts of Gujarat; see Shah *et al.* (1996a) for Gorakhpur division in eastern Uttar Pradesh; see Shah *et al.* (1996b) for north Bihar; see Kolavalli and Chicoine (1989) and Kolavalli *et al.* (1989) for Bankura and Purulia districts of West Bengal, eastern Uttar Pradesh and Kheda district in Gujarat; see Copestake (1986) for Madurai district in Tamil Nadu; see Shankar (1989,1992) for Allahabad district of Uttar Pradesh; see Pant (1988) for Bihar, Assam, West Bengal, eastern UP and Orissa; see Meinzen-Dick (1996), Meinzen-Dick and Sullins (1994) and Strosser *et al.* (1994) for several areas in Pakistan; and see Palmer-Jones and Mandal (1987) for Bangladesh.

10. In underdeveloped groundwater markets lacking in breadth as well as depth correspondingly, water trade affects a small proportion of farms and farm households, the scale of water transactions is small, and each seller deploys a

custom-made water sale contract in dealing with a buyer. In developed water markets, therefore, water is more widely sold on cash basis with commonly agreed norms of payment. In underdeveloped water markets, exchange of water for labour, crops and services is common, but more common is crop-sharing contracts in which, like land and labour in a standard tenancy contract, water too commands a crop-share, usually 1/3rd. In many ways, thus, the degree of development of a water market is quite akin to the degree of magnetisation of a barter economy.

11. Based on author's field visits to villages in Patna, Bhojpur, Muzaffarpur and East Champaran districts of Bihar in March 1996.

12. In 1988, Shah's survey of Navli village of Kheda district in Gujarat revealed that 24 private WEM owners had put up 65 kilo meter (km) of pipeline network with a total of nearly 600 outlets. Almost every parcel of land had 3-7 outlets of different WEMs opening into it, thus, offering buyers greater degrees of freedom for choosing between WEM owners (Shah 1993).

13. While buyers of water are the main beneficiaries from the pipelines, early sellers in central Gujarat's water markets were motivated mainly by the desire to establish monopoly position in the emerging new business by overcoming topographical constraints in supplying water to a large command. Once a seller in a village established a pipeline network, he drove out business of several others who used unlined field channels to convey water to the buyers' fields. In course of time, many such sellers were obliged to invest in pipeline systems or to quit as sellers and turn buyers. Perhaps, no irrigation system anywhere in the world invests so much to please its clients as these private spontaneous groundwater grids of central Gujarat do!

14. In the Vavidaimarudhur village, Janakarajan found a diesel WEM owner charging as high as Rs 40/hour. In village Kalpiravu in the tail end of Vaghai canal, six well owners who sold water to 140 buyers had emerged as village big-wigs. One of them, a grosser, supplied water for payment in crop produce, typically higher than its cash equivalence. In Pudukottai village, 5 hp diesel WEM owners charged Rs 15/hour, but 5 and 7.5 hp electric WEM owners too sold at Rs 10 and Rs 15/hour, respectively. Considering that electric WEM

owners in Tamil Nadu pay no electricity charges and spend less on wear and tear compared to diesel WEM owners, the only factor that can explain electric WEM owners' high water price is the monopoly power they enjoyed as water sellers.

15. In India, three types of contracts seem popular: a) labour contract in which the buyer will provide labour and draft power to the seller in return for water, b) crop sharing contract in which the seller provides only water while the buyer provides land, labour, manure and other inputs, and both share the crop, and c) crop and input sharing contract in which the buyer provides land and labour, the seller provides water, and both share other input cost and output. The terms of sharing output may vary across transactions depending primarily upon the nature of relationship between the buyer and the seller. The sellers' share in output ranged between 33% and 50% in the second type of contract, and between 50% and 66% in third type of contract.

16. A monopolistic water markets may sometimes help to achieve egalitarian rural income distribution, if resource poor farmers are given monopoly rights to lift and sell groundwater to the resource rich. As with the landless irrigation groups of Bangladesh, substantial transfers of wealth in the form of monopoly profit from water sale can be secured from the resource rich to poor water sellers through monopolistic water markets. However, as many field studies reveal, even in this situation, resource poor families as a class may be worse off than those with efficient water markets, since the elasticity of labour demand and wage rate with respect to irrigation use is high. High water prices will constrain irrigation expansion to sub-optimal levels, especially in water abundant areas. It is, therefore, certain that from output and distributional viewpoints, ensuring efficient water market should be an important goal for public policy for irrigation development (Shah 1993).

17. See, Deepak *et al.* 2005 and Nagaraj *et al.* 2005 in the context of hard rock Karnataka, and Razzaq *et al.* 2019 in the arid alluvial context of Pakistan Punjab.

18. A standard result from the theory of imperfect competition applied to the fragmented water markets would explain the relationship between water price charged by the sellers per hour of pumping (w), incremental pumping costs per hour (c), and the monopoly power enjoyed by water sellers (reflected in e, the elasticity of water demand function facing each) is derived as:

    w = e/(e-1).c

    When e is small (say, 1.4) as in an oligopoly, e/(e-1) will take a large value (of 2.5), and the price charged will be a large multiple of the incremental pumping cost, and under this, markets will be highly inefficient and also inequitable when most buyers are resource poor. Only in competitive water markets with a large number of water sellers competing with each other, will the value of e increase and of e/(e-1) decline to make water markets efficient (see, Shah 1993 for a fuller discussion). The [e/e-1] is a good indicator of the monopoly power enjoyed by water sellers in a community.

19. As they have done throughout eastern Uttar Pradesh and Bihar during the past decade.

20. As, for example, in Meerut district of western Uttar Pradesh.

21. There is growing evidence, in both eastern India and Bangladesh, that subsidies on WEM capital costs result in high density of under-utilised WEMs. In north Bihar and eastern UP, studies by Shah *et al.* (1996b) and Shah *et al.* (1996a) found the average annual pumpage of diesel WEMs to be 200-300 hours against 800-1,200 hours for electric WEMs subject to high FR in western UP, and over 1,200 hours in electric WEMs subject to high FR in Gujarat. Based on his study of Bangladesh, Morton writes, “Since the early period of DTW irrigation, there has been disappointment that the irrigated acreages, per unit of rated discharge have persistently fallen short ... of technically feasible (levels). STW performance is equally poor. Drop out rates have also been high and much equipment has gone out of use or diverted to non-irrigation purposes as a result” (Morton 1989:4).

22. For an exhaustive recent review of farm power pricing and its impact on groundwater markets, see Sidhu *et al.* (2020).

23. Augmentation tube wells are often established by the sides of a canal with the sole purpose of pumping groundwater into the canal to lower the water table as also to augment surface water availability to tail enders. In India, such tube wells were first set up along the Satluj-Yamuna canal, and Pakistan's SCARP tube well programme was also designed similarly. These met with uniform and resounding failure in serving their purpose.

24. The FR need not be zero or low. In India, the FR levied range from Rs. 0 in many south Indian states to Rs 50/hp/month in Uttar Pradesh and Rs 65/hp/month in Haryana. Compared to PR, the FR eliminates substantial costs involved in metering, meter reading and meter maintenance that has been estimated by some power utility managers to be Rs 40/month per connection. The FR dampens incentives to pilfer power. Above all, the most power supplied to farmers is off-peak load, and should normally be charged at lower than peak-load rates anyway. Many power-managers argue that but for the vast agricultural demand for off-peak load power, Indian power utilities would find it prohibitively expensive to serve the needs of domestic, commercial and industrial consumers. It is commonly thought that electricity boards are in the red because of FR, but insiders believe the situation to be contrary – electricity boards would be deeper in red with individual metering of WEMs. A compromise solution is to meter power at the level of a village community (Shah *et al.* 1996a).

25. Polices of the governments in Gujarat, Haryana and Uttar Pradesh have raised hopes that state governments will mobilise courage to raise FR. On this count, suspicion persists nevertheless, as Palmer-Jones aptly remarks, "it is one thing to raise the FR charged to farmers; it is quite another to get them to pay it even if it is still below the 'economic level'; furthermore, it may not ration the abstraction sufficiently" (Palmer-Jones 1994: 46).

26. In a study of water markets in the Fordwa area of Pakistan, Strosser and Kuper (1994) found that farmers located in the middle reach and the tail indulged in more intense groundwater trade than near the head or where canal water was plentiful and reliable. They also found that canal water supply decreased from the head to the tail of each branch or secondary canal or a water course, and from those located near the head of the system

to those near its tail end, while its unreliability followed the opposite pattern. As a result, "[t]he pumping rates of tube wells are higher for the non-perennial Azim distributary rather than the perennial Fordwah distributary with its more favourable (canal) water supply. The contribution of groundwater to total irrigation (varies) between 11% in Fateh to 93% in Azim 63-l water course" (Strosser and Kuper 1994: 8). Meinzen-Dick (1994) confirmed the same tendency in her study of Sone command in Bihar, using responses from a sample of 195 farmers from 13 villages in high, medium and low water delivery zones. Only 7% of the farmers in the high zone, as against 94% in low zone, reported canal water deliveries as 'worse than most parts of Sone system' and only half of the farmers in high zone, as against all farmers interviewed in medium and low zones, reported canal water supplies to be inadequate. A logistic regression showed that farmers in the low zone owned more tube wells than farmers in medium and high zones, and water markets were far more active in the low and medium zone than in high zone. Further, large holders had a higher likelihood of owning a tube well than small holders who depended far more heavily on purchased groundwater, and farmers depended on purchased water much more for rabi crops than kharif, suggesting the powerful role of water markets in increasing the cropping intensity.

27. In order to achieve both (b) and (c), the recommendations that the author made about electricity pricing and supply policies earlier are directly relevant.

28. Co-relative rights can have many attractive features from the viewpoint of equitable access. They (a) partially protect the vested rights of overlying owners, (b) offer higher certainty of tenure in times of shortages to all co-equal owners, and as co-equal rights do not lapse under non-use, these also protect the future rights of small holders who lag behind the affluent farmers in establishing modern WEMs, and (c) offer a reliable basis for the development of ground and surface water in an integrated format.

References

Acharyya, A, M Ghosh and R N Bhattacharya (2018): "Groundwater Market in West Bengal, India: Does It Display Monopoly Power?", *Studies in Microeconomics,* Vol. 6. No. 1-2, pp. 105-129.

Ahmed, Q F (1993): "Socialization of Minor Irrigation: A Strategy for Growth with Equity", in Kahnert, F, Levine, G (Eds.) *Groundwater Irrigation and the Rural Poor: Options for Development in the Gangetic Basin,* World Bank, Washington, DC, pp. 83-87.

Ananda, J and Aheeyar, M (2020): "An Evaluation of Groundwater Institutions in India: A Property Rights Perspective", *Environment, Development and Sustainability*, Vol. 22, No. 6, pp. 5731-5749.

Asian Development Bank (2012): *Shallow Tube well Irrigation in Nepal: Impacts of the Community Groundwater Irrigation Sector Project,* Impact Evaluation Study Report, ADB, Manila.

Asopa, V M and B H Dholakia (1983): *Performance Appraisal of Gujarat Water Resources Development Corporation: Vol. 1: Summary and Recommendations*, Center for Management in Agriculture, Indian Institute of Management, Ahmedabad.

Ballabh, V (1989): *Decline of A Novel Experiment: A Case Study of Group Irrigation Tube wells in Deoria District*, Paper presented at the Workshop on Efficiency and Equity in Groundwater Use and Management, Institute of Rural Management, Anand, January 30 - February 1.

Banerji, A, J V Meenakshi and G Khanna (2012): "Social Contracts, Markets and Efficiency: Groundwater Irrigation in North India", *Journal of Development Economics*, Vol. 98, No. 2, pp. 228-237.

Bhatia, B (1992): "Lush Fields and Parched Throats: Political Economy of Groundwater in Gujarat", *Economic and Political Weekly*, Vol. 27, No. 51/52, A142-A170.

Bromley, D (1993): "Common Property as A Metaphor: Systems of Knowledge, Resources and the Decline of Individualism", *The Common Property Resource Digest*, No. 27, September.

Butzer, K (1976): *Early Hydraulic Civilisation in Ancient Egypt,* University of Chicago Press, Chicago.

Central Groundwater Board (2017): *Dynamic Groundwater Resources of India*, Ministry of Water Resource, Government of India, New Delhi. Accessed at http://cgwb.gov.in/GW-Assessment/GWRA-2017-National-Compilation.pdf

Coase, R (1960): "The Problem of Social Cost", *Journal of Law and Economics*, Vol. 3, No. 1, pp.1-44.

Copestake, J G (1986): *Finance for Wells in a Hard-Rock Area of Southern Tamil Nadu*, Research Report No. 11, National Bank for Agricultural and Rural Development, Mumbai.

Deepak, S C, M G Chandrakanth and N Nagaraj (2005): *Groundwater Markets and Water Use Efficiency: The Case of Karnataka,* IWMI-Tata Water Policy Research Highlight, Vol. 12, pp. 1-7.

Dhawan, B D (1982): *Development of Tube well Irrigation in India*, Agricole Publishing Academy, New Delhi.

Dhawan, B D (1985): *Output Impact According to Main Irrigation Sources: Empirical Evidence from Four Selected States*, Paper presented at the INSA National Seminar on Water Management: Key to Development of Agriculture, at New Delhi, 28-30 April.

Dhawan, B D (1989): *Studies in Irrigation and Water Management*, Commonwealth Publishers, New Delhi.

Dhawan, B D (1990): *Studies in Minor Irrigation: with Special Reference to Groundwater*, Commonwealth Publishers, New Delhi.

Dhawan, B D and K J Satya Sai (1994): "Economic Linkages among Irrigation Sources: A Study of the Beneficial Role of Canal Seepage", in Ruth Suseela Meinzen-Dick, and Mark Svendsen (Eds.) *Future Directions for Indian Irrigation*, International Food Policy Research Institute, Washington.

Durga, N R, P Gyan, S Verma, S Saini and D Kumar (2020): "Catalysing Competitive Irrigation Service Markets in North Bihar: The Case of Chakhaji Solar Irrigation Service Market", in P B Shirsath, S Saini, N Durga, D Senoner, N Ghose, S Verma, A Sikka (Eds.), *Compendium on Solar Powered Irrigation Systems in India*, CGIAR Research Programme on Climate Change, Agriculture and Food Security, Wageningen, Netherlands, pp. 47-50.

Fujita, K (2005): *Changes of Groundwater Markets in Bangladesh and West Bengal*, Paper presented at the Asian Society of Agricultural Economists 4th International Conference, August 20-22, Alor Setar, Kedah, Malaysia.

Fujita, K, A Kundu and W M H Jaim (2003): "Groundwater Market and Agricultural Development in West Bengal: Perspectives form A Village Study", *The Japanese Journal of Rural Economics*, Vol. 5, pp. 51-65.

Gazmuri, R S and M W Rosegrant (1994): *Chilean Water Policy: The Role of Water Rights, Institutions and Markets*, Paper prepared for the Irrigation Support Project for Asia and the Near East (ISPAN), aUSAID-supported project.

Government of Uttar Pradesh (1993): *Recommendations of High Level Committee under the Chairmanship of Dr B D Pathak*, Central Ground Water Board, September 10.

Gupta, E (2019): "The Impact of Solar Water Pumps on Energy-Water-Food Nexus: Evidence from Rajasthan, India", *Energy Policy*, Vol. 129, No. C, pp. 598-609, Accessed at https://www.scopus.com/

Howes, M (1985): *Whose Water? An Investigation of the Consequences of Alternative Approaches to Small Scale Irrigation in Bangladesh*, Bangladesh Institute of Development Studies, Dhaka.

Janakarajan, S (1994): "Trading in Groundwater: A Source of Power and Accumulation", in M Moench (Eds), *Selling Water: Conceptual and Policy Debates over Ground Water Markets in India*, VIKSAT, Ahmedabad, pp. 47-58.

Janakarajan, S (1995): *Consequences of Aquifer Over-exploitation: The Case of Prosperity versus Deprivation,* Paper presented at the International Conference on the Political Economy of Water in South Asia: Rural and Urban Action and Interaction, Madras Institute of Development Studies, Madras, January 5-8.

Kahnert, F and L Gilbert (Eds) (1993): *Ground Water Irrigation and the Rural Poor: Options for Development in the Gangetic Basin*, The World Bank, Washington DC.

Kajisa, K and T Sakurai (2005): "Efficiency and Equity in Groundwater Markets: The Case of Madhya Pradesh, India", *Environment and Development Economics*, Vol. 10, No. 6, pp. 801-819.

Kemper, K E (1996): "The Cost of Free Water: Water Resources Allocation and Use in the Curu Valley, Ceara, Northeast Brazil", *Linkoping Studies in Arts and Science No* 137 *,* Linkoping University, Sweden.

Khair, S M, S Mushtaq, R J Culas and M Hafeez (2012): "Groundwater Markets under the Water Scarcity and Declining Watertable Conditions: The Upland Balochistan Region of Pakistan", *Agricultural Systems*, No. 107, pp. 21-32.

Kishore, A (2004): "Understanding Agrarian Impasse in Bihar", *Economic and Political Weekly*, Vol. 39, No. 31, pp. 3484-3491.

Kishore, A, P K Joshi and D Pandey (2014): *Droughts, Distress, and Policies for Drought Proofing Agriculture in Bihar, India*, Discussion Paper 1398, International Food Policy Research Institute, Washington DC.

Kolavalli, S (1986): *Economic Analysis of Conjunctive Use of Water: The Case of Mahi-Kadana Irrigation Project in Gujarat State, India,* Unpublished Ph.D thesis, University of Illinois, Urbana I.

Kolvalli, S and D L Chicoine (1989): "Groundwater Markets in Gujarat, India", *International Journal of Water Resources Development*, Vol. 5, No. 1, pp. 38-43.

Kolavalli, S, and N Shah (1993): "Management of Public Tube Wells in Uttar Pradesh", in F Kahnert, G Levine (Eds.) *Groundwater Irrigation and the Rural Poor: Options for Development in the Gangetic Basin*, World Bank, Washington DC, pp. 131-144.

Kolavalli, S, A H Kalro and V N Asopa (1989): *Issues in the Development of Groundwater Resources in East UP,* Indian Institute of Management, Ahmedabad.

Kumar, M D (1995): *Tube well Turnover: A Study of Groundwater Irrigation Organisations in Mehsana*, VIKSAT, Ahmedabad.

Kumar, M D (2000): "Institutions for Efficient and Equitable Use of Groundwater: Irrigation Management Institutions and Water Markets in Gujarat, Western India", *Asia-Pacific Journal of Rural Development*, Vol. 10, No. 1, pp. 52-65.

Kumar, M D (2007): *Groundwater Management in India: Physical, Institutional and Policy Alternatives,* Sage Publications, New Delhi.

Kumar, M D, and P J Patel (1995): "Depleting Buffer and Farmers Response: Study of Villages in Kheralu, Mehsana, Gujarat", in Moench, M (Ed.), *Electricity Prices: A Tool for Groundwater Management in India?,* VIKSAT-Natural Heritage Institute, Ahmedabad.

Kumar, M D, B Iyer and V Agarwal (2004): *Can North Gujarat's Agrarian Economy Thrive with Less Groundwater Use? A Simulation Study Using Linear Programming in Banaskantha District*, Paper presented at Annual Partners' Meet of the IWMI-Tata Water Policy Research Program, Anand.

Kuriachen, P, A Suresh, K S Aditya, P Venkatesh, B Sen and S S Yeligar (2021): "Irrigation Development and Equity Implications: The Case of India", *International Journal of Water Resources Development*, p. 1-17. Accessed at https://doi.org/10.1080/07900627.2021.1912715

Lall, P and S Pachauri (1994): *Agriculture, Irrigation and Water Markets: A Community Perspective - Case Studies of Three Villages in Lalitpur District of Uttar Pradesh*, Ecotech Services (India) Pvt. Ltd., New Delhi.

Lowdermilk, M K, A C Early, and D M Freeman (1978): "Farm Irrigation Constraints and Farmers' Responses: Comprehensive Field Survey in Pakistan", *Water Management Research Technical Report 48*, Colorado State University, September.

Mandal, M A S (1989): *Groundwater Irrigation by Landless Pump Groups in Bangladesh*, Paper presented at the Workshop on Efficiency and Equity in Groundwater Use and Management, Institute of Rural Management Anand, January 30-February 1.

Mandal, M A S (1993): "Groundwater Irrigation in Bangladesh: Access, Competition, and Performance", in F Kahnert and G Levine (ed) *Groundwater Irrigation and the Rural Poor: Options for Development in the Gangetic Basin*, The World Bank, Washington.

Manjunatha, A V, S Speelman, S Aravindakshan, T S Amjath Babu and P Mal (2016): "Impact of Informal Groundwater Markets on Efficiency of Irrigated Farms in India: A Bootstrap Data Envelopment Analysis Approach", *Irrigation Science*, Vol. 34, No. 1, pp. 41-52.

Mehanna, S, R Huntington and R Antonius (1984): *Irrigation and Society in Rural Egypt*, Cairo Papers in Social Science, Vol. 7, Monograph 4, The American University in Cairo, Egypt.

Meinzen-Dick, R (1994): "Adequacy and Timeliness of Irrigation Supplies under Conjunctive Use in the Sone Irrigation System, Bihar", in Swendsen, Mark and Ashok Gulati (Eds), *Strategic Change in Indian Irrigation,* ICAR, New Delhi and IFPRI, Washington.

Meinzen-Dick, R (1996): *Groundwater Market in Pakistan: Participation and Productivity*, Research Report 105, International Food Policy Research Institute, Washington.

Meinzen-Dick, R and M S Mendonza (1996): "Alternative Water Allocation Mechanisms: Indian and International Experience", *Economic and Political Weekly*, Vol. 31, No. 13, pp. A25-A30.

Meinzen-Dick, R and M Sullins (1994): *Water Markets in Pakistan: Participation and Productivity*, International Food Policy Research Institute, Washington.

Ministry of Agriculture (1976): *Report of the National Commission on Agriculture*, Government of India, New Delhi.

Ministry of Irrigation (1972): *Report of the Irrigation Commission*, Government of India, New Delhi.

Moench, M (1992): "Chasing the Watertable-Equity and Sustainability in Groundwater Management", *Economic and Political Weekly*, Vol. 27, No. 51-52, pp. A171-A171.

Moench, M (1993): *When Good Water Becomes Scarce: Objectives and Criteria'*, VIKSAT/Pacific Institute Paper, Ahmedabad.

Moench, M (1994a): "Approaches to Groundwater Management: To Control or Enable?", *Economic and Political Weekly*, Vol. 29, No. 39, pp. A135-A146.

Moench, M (1994b): *Groundwater Policy: Issues and Alternatives in South Asia*, Natural Heritage Institute, San Francisco.

Morton, J (1989): *Tube well Irrigation in Bangladesh*, *ODI-IIMI Irrigation Management Network Paper 89/2d,* December.

Mottaleb, K A, T J Krupnik, A Keil and O Erenstein (2019): "Understanding Clients, Providers and the Institutional Dimensions of Irrigation Services in Developing Countries: A Study of Water Markets in Bangladesh", *Agricultural Water Management*, Vol. 222, pp. 242-253.

Mukherji, A (2003): "Groundwater Development and Agrarian Change in Eastern India", *IWMI-Tata Comment,* 9, pp. 1-11.

Mukherji, A (2004): "Groundwater Markets in Ganga-Meghna-Brahmaputra Basin: Theory and Evidence", *Economic and Political Weekly,* Vol. 30, No. 31, pp. 3514-3520.

Mukherji, A (2007a): "The Energy-Irrigation Nexus and Its Impact on Groundwater Markets in Eastern Indo-Gangetic Basin: Evidence from West Bengal, India", *Energy Policy*, Vol. 35, No. 12, pp. 6413-6430.

Mukherji, A (2007b): *When Wells are Welfare and not Threat to Farmers' Well-being: Groundwater Markets and Politics in West Bengal, India*, Paper presented at the Conference on Sustainable Development and Livelihoods, Delhi School of Economics, 6-8 February.

Mukherji, A (2008a): *The Paradox of Groundwater Scarcity Amidst Plenty and Its Implications for Food Security and Poverty Alleviation in West Bengal, India: What Can be Done to Ameliorate the Crisis?,* Paper presented at the 9th Annual Global Development Network Conference, Brisbane, Australia, 29-31 January.

Mukherji, A (2008b): "Spatio-Temporal Analysis of Markets for Groundwater Irrigation Services in India: 1976-1977 to 1997-1998", *Hydrogeology Journal*, Vol. 16, No. 6, pp. 1077-1087.

Mukherji, A (2009): *Electricity Subsidies and Reforms and Its Impact on Groundwater Use in States of Gujarat and West Bengal, India*, World Water Week in Stockholm, Sweden, 16-22 August.

Mukherji, A (2020): "Sustainable Groundwater Management in India Needs a Water-Energy-Food Nexus Approach", *Applied Economic Perspectives and Policy*, Vol. 44, No. 1, pp. 394-410.

Mukherji, A, M Buisson, A Mitra, A Sarkar and Yashodha (2021): *Sonar Bangla Revisited: Groundwater Development and Agrarian Change in Bangladesh and West Bengal since the 1970*, Final Report ACIAR Small Research Activity No. WAC/2020/18 IWMI, Colombo.

Nagaraj, N, A H Suvarna Kumar, M G Chandrakanth (2005): *Economic Analysis of Groundwater Markets in Central Dry Zone of Karnataka*, Working Paper No. No. 43785, IWMI-Tata Water Policy Research Highlight, International Water Management Institute, Columbo.

Naz, F (2015): "Water, Water Lords, and Caste: A Village Study from Gujarat, India", *Capitalism Nature Socialism*, Vol. 26, No. 3, pp. 89-101.

Padmanabhan B S (1988): "Groundwater Irrigation: Delayed Recognition of Role", *The Hindu Survey of Agriculture,* New Delhi.

Palanisami, K (1994): "Evolution of Agricultural and Urban Water Markets in Tamil Nadu, India", Appendix D in M W Rosegrant and R Gaznuri (Eds.), *Tradable Water Rights: Experiences in Reforming Water Allocation Policy*, Irrigation Support Project for Asia and Near East, USAID.

Palmer-Jones, R (1994): "Groundwater Markets in South Asia: A Discussion of Theory and Evidence", in Marcus Moench (Eds.), *Selling Water: Conceptual and Policy Debates over Groundwater Markets in India*, VIKSAT-Pacific Institute-Natural Heritage Institute.

Palmer-Jones, R W and M A S Mandal (1987): *Irrigation Groups in Bangladesh*, ODI/IIMI Irrigation Management Network 87/2c, Overseas Development Institute, London.

Pant, N (1988): *Groundwater Issues in Eastern India*, Paper prepared for the International Food Policy Research Institute-TNAU Workshop on Policy Related Issues in Indian Irrigation, Ootakamand, April 26-28.

Pant, N (1993): "Performance of the World Bank Tube Wells in India", in F Kahnert and G Levine (Eds.) *Groundwater Irrigation and the Rural Poor: Options for Development in the Gangetic Basin,* World Bank, Washington, DC, p. 119-130.

Pant, N (2004): Trends in Groundwater Irrigation in Eastern and Western UP, *Economic and Political Weekly*, Vol. 39, No. 31, pp. 3463-3468.

Planning Commission (2007): *Report of the Expert Group to Review the Issue of Groundwater Ownership in the Country,* Government of India, New Delhi.

Qureshi, A S, M Akhtar and T Shah (2004): Role of Changing Pricing Policies on Groundwater Development in Pakistan, *Journal of Applied Irrigation Science,* Vol. 39, No. 2, pp. 329-342.

Rao, D S K (1993): "Groundwater Overexploitation through Bore-hole Technology", *Economic and Political Weekly*, Vol. 28, No. 52, pp. A129-A134.

Rao, V M (1978): "Linking Irrigation with Development: Some Policy Issues", *Economic and Political Weekly*, Vol. 13, No. 24, pp. 993-997.

Rawal, V (2002): "Non-Market Interventions in Water-Sharing: Case Studies from West Bengal, India", *Journal of Agrarian Change*, Vol. 2, No. 4, pp. 545-569.

Razzaq, A, P Qing, M A U R Naseer, M Abid, M Anwar and I Javed (2019): "Can the Informal Groundwater Markets Improve Water Use Efficiency and Equity? Evidence from a Semi-arid Region of Pakistan", *Science of the Total Environment*, Vol. 666, pp. 849-857.

Rinaudo, J D (1994): *Development of a Tool to Assess the Impact of Water Markets on Agricultural Production in Pakistan*, Thesis submitted for obtaining the

Diploma dapos; Etudes Approfondiesg Economie du Developpement Agricole, Agro-Alimentaire et Rural.

Rinaudo, J D, P Strosser and T Rieu (1994): *Water Market Development and Production Strategies: Are Farmers Rational?,* Paper presented at the International Conference on Water Resources, Bari, September.

Rosegrant, M W (1994): "Tradable Water Rights: Abstract of Panel Presentation", in *Future Directions for Implementing Water Policy*, Report on a USAID-sponsored Workshop held at the University of Maryland, University College Conference Center, Maryland, USA, 28-29 April.

Rosegrant, M and R Gazmuri (1994): *Reforming Water Allocation Policy through Markets in Tradable Water Rights: Lessons from Chile, Mexico and California*, EPTD Discussion Paper 6, International Food Policy Research Institute, Washington DC.

Saleth, R M (1993): *Efficacy of Power Tariff as an Instrument of Groundwater Management: Implications for Sustainability, Efficiency and Equity*, Paper Presented at the Workshop on Co-management of Power and Groundwater: Issues in Sustainability and Equity, Tata Energy Research Institute, Delhi, 12-13 February.

Saleth, R M (1994a): "Groundwater Markets in India: A Legal and Institutional Perspective", *The Indian Economic Review*, Vol. 39, No. 2, pp. 157-176.

Saleth, R M (1994b): *Water Rights System: Towards an Institutional Option for the Sustainable Management of Water Resources in India*, Institute of Economic Growth, Delhi.

Saleth, R M (2014): "Water Markets in India: Extent and Impact", in K W Easter and K Q Huang (Eds) *Water Markets for the 21st Century: What Have We Learned?, Global Issues in Water Policy, Vol. 11*, Springer, New York.

Shah, T (1985): *Transforming Groundwater Markets into Powerful Instruments of Small Farmer Development: Lessons from the Punjab, Uttar Pradesh and Gujarat*, ODI Irrigation Management Network Paper No. 11d, Overseas Development Institute, London.

Shah, T (1986): *Groundwater Markets in Water Scarce Regions: Field-notes from Karimnagar District, Telangana, Andhra Pradesh*, Institute of Rural Management, Anand.

Shah, T (1993): *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy*, Oxford University Press, Bombay.

Shah, T (1995): "Liberalisation and Indian Agriculture: New Relevance of Farmer Co-operatives", *Indian Journal of Agricultural Economics*, Vol. 50, No. 3, pp. 488-509.

Shah, T (1996a): *Design of an Irrigators' Organisation: A Proposal for the Chandrawadi Irrigation Project, Junagadh* (internal paper), The Policy School, Anand.

Shah, T (1996b): *Organisation for the Bhagiratha Mini Water-grid, Andhra Pradesh: Outline of a Design and Its Framework* (internal paper), The Policy School, Anand.

Shah, T (2009): *Taming the Anarchy: Groundwater Governance in South Asia,* RFF Press, Washington DC.

Shah, T and V Ballabh (1995): "The Social Science of Water Stress: An Exploratory Study of Water Management Institutions in Banaskantha District, Gujarat", in M Moench (Eds), *Groundwater Management: The Supply Dominated Focus of Traditional NGO and Government Efforts,* VIKSAT, Ahmedabad, pp. 42-61.

Shah, T and S Bhattacharya (1993): *Farmer Organisations for Lift Irrigation: Irrigation Companies and Tube well Co-operatives of Gujarat*, ODI Irrigation Management Network Paper 26, Overseas Development Institute, London.

Shah, T and S D Chowdhury (2017): Farm Power Policies and Groundwater Markets: Contrasting Gujarat with West Bengal (1990-2015), *Economic and Political Weekly*, Vol. 52, No. 25-26, pp. 39-47.

Shah, T and K V Raju (1988): "Working of Groundwater Markets in Andhra Pradesh and Gujarat: Results of Two Village Studies", *Economic and Political Weekly*, Vol. 26, No. 3, pp. A23-A28.

Shah, T, R Indu and S Paleja (1996a): *Muscle, Diesel Electrical: Energy-Irrigation Dynamics in Eastern Uttar Pradesh*, Unpublished Report for the Water Management Institutions Research Program.

Shah, T, V Ballabh and Others (1996b): *Groundwater Markets in North Bihar*, Unpublished Report for the Water Management Institutions Research Program.

Shankar, K (1989): *Working of Private Water Markets in Eastern UP*, Paper Presented at a Workshop on "Efficiency and Equity in Groundwater Use and Management", Institute of Rural Management, Anand, January 30-February 1.

Shankar, K (1992): *Dynamics of Groundwater Irrigation*, Segment Books, New Delhi.

Sidhu, B S, M Kandlikar and N Ramankutty (2020): "Power Tariffs for Groundwater Irrigation in India: A Comparative Analysis of the Environmental, Equity, and Economic Tradeoffs", *World Development*, 128. Accessed at https://doi.org/10.1016/j.worlddev.2019.104836.

Singh, C (1992) (Eds): *Water Law in India*, Indian Law Institute, New Delhi.

Singh, D R and P Arya (undated): *Water Markets and Its Implications to Small Farmers*. Accessed at https://www.iari.res.in/files/Divisions/Water%20Markets%20and%20its%20implications%20to%20small%20farmers.pdf

Singh, O, A Kasana and T Sharma (2020): "Groundwater Irrigation Market Patterns and Practices Over an Agriculturally Developed Province of North-West India", *Geo Journal*, Vol. 85, No. 3, pp. 703-729.

Smith, R, H T Nelson and T Roe (2015): "Groundwater and Economic Dynamics, Shadow Rents and Shadow Prices: The Punjab", *Water Economics and Policy,* Vol. 1, No. 3.

Strosser, P and M Kuper (1994): *Water Markets in the Fordwah/Eastern Sadiqia Area: An Answer to Perceived Deficiencies in Canal Water Supplies?,* Working Paper No. 30, International Irrigation Management Institute, Colombo.

Strosser, P and R Meinzen-Dick (1994): Groundwater Markets in Pakistan: An Analysis of Selected Issues, in M Moench (Ed), *Selling Water: Conceptual* *and Policy Debates over Groundwater Markets in India*, VIKSAT-Pacific Institute-Natural Heritage Institute, Ahmedabad.

Sugden, F (2014): *Landlordism, Tenants and the Groundwater Sector: Lessons from Tarai-Madhesh, Nepal,* IWMI Research Report 162, International Water Management Institute, Colombo.

Tata Energy Research Institute (1994): *Co-management of Power and Groundwater Resources: Issues in Sustainability and Equity in Groundwater Scarce Areas*, Report for the Ford Foundation, TERI, New Delhi.

Thobani, M (1995): *Tradable Property Rights to Water: How to Improve Water Use and Resolve Water Conflicts,* FPD Note No. 34, The World Bank, Washington.

Tyagi, B N (1994): *Requirement of Electric Power for Agriculture in Uttar Pradesh*, (Unpublished Study), World Bank, New Delhi.

Urfels, A, A J McDonald, T J Krupnik and P R van Oel (2020): "Drivers of Groundwater Utilization in Water-limited Rice Production Systems in Nepal", *Water International*, Vol. 45, No. 1, pp. 39-59.

Veeman, T S (1978): "Water Policy and Water Institutions in Northern India: The Case of Groundwater Rights", *Natural Resources Journal*, Vol. 18, No 3, pp. 569-587.

Whittington, D, D T Lauria and Mu Xinming (1991): "A Study of Water Vending and Willingness to Pay for Water in Onitsha, Nigeria", *World Development*, Vol. 19, Nos. 2 and 3, pp. 179-198.

Whittington, D, D T Lauria, A O Daniel and Mu Xinming (1989): "Water Vending Activities in Developing Countries: A Case Study of Ukunda, Kenya", *International Journal of Water Resources Development*, Vol. 5, No. 3, pp. 158-168.

Wood, G (1995): *Private Provision after Public Neglect: Opting Out with Pump Sets in North Bihar,* Paper presented at the International Conference on the Political Economy of Water in South Asia: Rural and Urban Action and Interaction, Madras Institute of Development Studies, Madras, January 5-8.

Wood, G and R Palmer-Jones (1991): *Water Sellers*, IT Press, London.

World Bank (1994): *Peru: A User-Based Approach to Water Management and Irrigation Development*, The World Bank, Washington.

Yashodha (2020): "Do Buyers have Bargaining Power? Evidence from Informal Groundwater Contracts", *PLoS ONE*, Vol. 15, No. 9. Accessed at https://doi.org/10.1371/journal.pone.0236696

Glossary

Aquifer	Underground formation containing water.
Area of influence of a well	Area surrounding a well from which water flows into it when pumped.
Autarky	Absence of market transactions due to self-sufficiency.
Recharge	Enhancement of water contained in the aquifer due to seepage of water from rainfall, canals or field irrigation return flows.
Water Extraction Mechanism	Dug or borewells fitted with traditional or modern water lifting device.
Water logging	A condition caused by excessive recharge in which groundwater table rises to the root zone of crops.
Well-interference	Wells with overlapping areas of influence interfering with each other when both are pumped simultaneously.

About The Author

Dr. Tushaar Shah, an economist, water-energy policy specialist and public policy specialist, is Emeritus Scientist of the International Water Management Institute, Colombo and Professor Emeritus of the Institute of Rural Management Anand (IRMA). Over the past 40 years, Shah's main research interests have been in two fields: farmer organisations, and water institutions and policies. In both these fields, he has published extensively, and his writings have helped to shape national debates and public policies. The research he published on water markets has generated wide interests in India and abroad, and water markets soon emerged as a distinct field of study in India, Pakistan, Bangladesh and China. This new field attracted hundreds of researchers and led to a voluminous empirical literature during the 1990s and thereafter. Studies by the faculty and students of IRMA under his leadership during the 1990s kickstarted a debate on how best to design robust member organisations and sowed the seeds of new generation farmer cooperatives. Like-wise, field research by the IWMI-Tata Water Policy Program that Shah founded and led had influenced Government of Gujarat's Suryashakti Kisan Yojana (SKY), and Government of India's Pradhan Mantri Krishi Sinchai Yojana (PMKSY) as well as US $ 45 billion KUSUM scheme for solarising India's groundwater economy.

His policy research on groundwater governance won him Consultative Group of International Agricultural Research (CGIAR) Outstanding Scientist Award in 2002, UN Water-for-Life Award for Best Practices in Water Management Research in 2014 and Distinguished Associate Award of International Association of Hydro geologists in 2018. For over a decade, Shah has been a regular invitee to the annual pre-budget consultations with Union Finance Minister in the field of agriculture and rural development. In 2019, Shah was invited to brainstorm with the Prime Minister and Niti Ayog along with 40 economists, industrialists and thought leaders on "Economic Policy: The Road Ahead" for NDA II.

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