1 The Agricultural Groundwater Revolution: Setting the Stage

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Over the last 50 years groundwater development has played a fundamental role in agricultural production in many parts of the developing world. For example, groundwater now accounts for approximately 50% of all irrigation supply in South Asia and perhaps two-thirds of supply in the grain belts of North China. The rapid growth in use in these and other regions has played a vital role in maintaining the rise in grain output associated with the Green Revolution, transforming production and livelihood strategies for millions of small farmers and providing food to growing urban centres.

Groundwater use of course has not come without problems, both in terms of sustainability and quality. In India and the areas of China just mentioned, plummeting water tables are notorious and bring into question the future use of the resource. In other regions, particularly in the Middle East and North Africa, groundwater is taken from fossil sources with no chance of recharge and so any utilization has to be considered part of a longer-term development strategy rather than 'sustainable use'. In addition to use within the agricultural sector, competition for groundwater from cities makes it harder for farmers to maintain supplies, and drawdown by farmers themselves can make critical rural domestic supplies more costly to obtain. Pollution from the very farming systems supported by groundwater, as well as from industry, increasingly degrade the utility of groundwater resources. High rates of use in many areas have severed the links between surface and groundwater resources, damaging ecosystems in their own right and reducing the livelihood generation options that rural residents rely on.

While it is the problem of overuse that garners the most attention, other parts of the developing world have yet to take full advantage of the livelihood-generating and poverty-reducing potential of groundwater. Some countries in sub-Saharan Africa and Central America provide such examples. However, even within regions commonly associated with overuse, there are areas with little utilization. While fears of a groundwater boom turning to bust are perhaps

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highest in India, the eastern regions of the country have hardly tapped the development potential. As shown in this book, similar areas of limited utilization exist even in the North China Plain, another region where concern over overexploitation is the norm.

The problems for groundwater management in the developing world are not unique to either groundwater or the region. However, groundwater management, especially in a developing country context, does pose unique sets of management challenges. Unlike surface water, groundwater is 'invisible' and difficult to conceptualize and to measure. Further, it must be understood in terms of timescales much longer than those used in surface water management, with lags between rainfall, storage and use best thought of in terms of years, decades or even centuries. Groundwater is in many respects an open-access resource, with any particular aquifer typically underlying multiple farmers, any of whom can extract the resource with relatively cheap and simple pump technology. In many densely populated developing countries, this means that management would involve the coordination of hundreds or even thousands of users, a challenge made even more difficult for user groups or governments by insufficient resources for basic measurement and coordination. Understanding the physics of groundwater movement and measurement, the sociology of groundwater users, the political economy of the water and agricultural sectors and the laws and institutions that have been, or might be, brought to bear is necessary if we are to come to terms with the challenges of groundwater use and management.

Recognizing the value that groundwater can have for poverty alleviation, livelihood generation and global food supply, the threats to, and continued opportunities for, groundwater use and the multi-disciplinary nature of groundwater management problems, the Comprehensive Assessment of Water Management in Agriculture funded a research programme on the state of groundwater use and governance in the developing world and suggested options for the future. The goal of this book is to synthesize that work and provide an overview of the issues and options in agricultural groundwater use across the developing world. To accomplish this goal, the book calls on the work of regional and subject matter experts from Asia, Africa, Australia, Europe, Latin America and North America with expertise in anthropology, biology, economics, geography, hydrology, law and political science. Together this group of authors must be one of the most geographically and disciplined diverse groups ever to come together to address agricultural groundwater challenges.

The book is divided into three parts plus two final chapters. Part I provides regional overviews of agricultural groundwater systems covering much of the developing world. The regions include 'traditional' use areas such as South Asia, China and the Middle East/North Africa where groundwater already contributes substantially to existing agricultural economies. It also includes two areas, sub-Saharan Africa and Central America, where groundwater contributions to agriculture have been less well recognized or developed. Together these chapters tell a story of the similarity and difference in both the present contribution of groundwater to agriculture and livelihood across the developing world and the challenges for the future.

Part II presents an overview of three major governance paradigms that have been, or might be, employed to address the challenges facing groundwater management. The paradigms include what might at first be considered two opposing schools of thought, one focusing on community approaches or self-management by users and the other on instrumental approaches, i.e. formal laws, regulations and pricing requiring higher government involvement. Chapter 9, the final one in Part II, highlights the possibilities for 'adaptive approaches' that acknowledge the possibilities and limitations of community and instrumental solutions, and pushes both users and researchers to focus not just on groundwater resources but also on the livelihood of groundwater users and their options, including options outside of agriculture.

Part III provides a series of case studies that examine how these governance paradigms have actually functioned on the ground. Chapters include community management of groundwater resources through water harvesting, the role of indirect instruments such as electricity policy and farmer adaptation to changing resource conditions. The chapters also highlight the experience of the varying approaches in the three main agricultural groundwater economies of the developed world: Spain, the USA and Australia. They provide an opportunity to reflect on why approaches to groundwater management that might work under one set of socio-ecological conditions might not work in another.

One of the key points woven through all of the chapters is that information is a critical element for groundwater management, no matter what region. Chapter 16 further highlights this issue by examining global information sharing in groundwater management.

Chapter 17 concludes the book with an overview of the state of affairs in agricultural groundwater use in the developing world, the opportunities and threats for the resource to continue contributing to global food supply and to lifting farmers out of poverty and into the future, agricultural or not, that they most desire. The conclusion is based on the contents of the book, but also draws in additional resources of the comprehensive assessment so as to cover topics not directly addressed, or not addressed in great detail, in this book.

While it is impossible to fully summarize the findings of so many authors with so many different perspectives studying such a wide geographic area, a generalized set of conclusions does emerge from the chapters as a whole:

1. Information gaps but underestimated use – there are substantial gaps in basic information on groundwater availability and agricultural use. In general, however, agricultural groundwater use appears to be substantially underestimated in most published figures.

2. Major impacts across settings – groundwater use in agriculture has increased substantially over the last 50 years and played a significant role in increased food production and livelihood security across broad areas of the world with wide-ranging climatic and socio-economic settings.

3. Threats to the future but continued expansion – while there are well-grounded fears that overdraft may threaten the future of the resource and the activities it supports in many regions (e.g. western and southern India, parts of northern China), overall agricultural groundwater use continues to grow, sometimes at

an increasing rate. Still, there are regions where possibilities for use have not been fully exploited (e.g. parts of sub-Saharan Africa, eastern India).

4. Boom and bust trajectories – there is a tendency for agricultural groundwater economies to move along a trajectory of initial utilization, agrarian boom, growing scarcity and eventually, in some cases, bust as groundwater tables fall.

5. Special management challenges – developing institutions to better manage the boom and bust trajectory is complicated by the physical properties of the resource and their interaction with social systems. Groundwater is often 'invisible' and thus difficult to measure. It must be understood in terms of years, decades or centuries. The vast areal extent and number of users of many aquifers, and low-cost means of abstraction, make groundwater subject to 'open access' problems. The political economy of agriculture and the sometimes stark social trade-offs inherent in decisions to control use make institutional action difficult.

6. Emerging paradigms – paradigms for tackling the challenges of groundwater management are emerging and being used with limited success. These paradigms can be thought of as mitigation – e.g. community-based agreements to regulate use as well as more formal economic and legal measures – and adaptation measures to facilitate farmers' ability to adjust to changing groundwater conditions.

7. Influence and options from other sectors – irrespective of the management approach taken, it must be remembered that groundwater outcomes are often driven in part by forces outside the water sector including agricultural and energy policy as well as broader political aims and processes. This increases the complexity of the problem but also the range of possible solutions.

8. No single 'best practice' – groundwater management approaches that work in one country or region may not do so in another. This is because of variation in the physical properties of groundwater as well as in the socio-economic and political strengths, weaknesses and desires of the societies involved. In this sense, groundwater management solutions will be local solutions.

9. Costs of failure and value of success – the establishment and maintenance of groundwater management regimes clearly has costs and can pit current use against future options. However, without active management, the total number of 'losers' including resource users, the environment and society as a whole is likely to be higher and more skewed towards the poorest user groups, than if action were taken.

We hope you will enjoy the book and that it will inspire new thinking, criticism, debate and, hopefully, positive action.