Water Policy Briefing

Issue 4 IWMI-Tata Water Policy Program Putting research knowledge into action

The Socio-Ecology of Groundwater in India

Recent research shows that groundwater irrigation has surpassed surface irrigation as the primary source of food production and income generation in many rural areas. The key question for policy makers and planners is how to tap this resource without exhausting the supply. The mind-set and water management skills need to shift from resource development to resource planning.

IWMI-TATA
Water Policy Program

The Socio-Ecology of Groundwater in India

Many people still believe that India's irrigation water mainly comes from canal irrigation systems. While this may have been true in the past, recent research shows that groundwater irrigation has overtaken surface-water irrigation as the main supplier of water for India's crops. Groundwater now sustains almost 60% of the country's irrigated area. Even more importantly, groundwater now contributes more to agricultural wealth creation than any other irrigation source (see Fig. 1).

Groundwater use has increased largely because it is a 'democratic resource,' available to any farmer who has access to a pump. Accessibility has led to widespread exploitation of the resource, by farmers grateful for a reliable irrigation-water source. In turn, this has led to high levels of groundwater use being associated with high population density. But it is a myth that groundwater use is high only where supplies are high. Such findings are worrying, because the consequences of overexploitation of this precious and productive resource can be catastrophic.

The research highlighted in this briefing identifies four stages of groundwater development. To avert potential disaster and maximize benefits of groundwater as a force for poverty reduction, new policies are needed at each of these four stages. It is crucial that policymakers intervene at these critical stages to manage both the supply and demand aspects of groundwater use. Urgent priorities are areas with low supplies of renewable groundwater but alarmingly high groundwater use, such as Tamil Nadu, Gujarat, Maharashtra, Andra Pradesh, Karnataka, Punjab and Haryana.

Groundwater has emerged as the primary democratic water source and poverty reduction tool in India's rural areas. It now contributes more to rural wealth creation than surface-water irrigation. Yet State irrigation departments currently focus most of their manpower and budgetary resources on centrally-created and managed large canal irrigation systems, allocating only a fraction to groundwater resources.

This policy imbalance is a symptom of the fact that the increase in the importance of groundwater over the past 25 years has largely escaped government notice. Why was this? Because the groundwater boom happened in the private, 'informal' sector, while public agencies played only an indirect role.

The explosive growth of India's groundwater economy is a result of people's resourcefulness. They sink tube wells or dig shallow wells, and connect a pump to irrigate crops that they could not otherwise grow. This approach doesn't rely on government planning, canal infrastructure or deliveries of water by the irrigation department.

Having control over their water means farmers invest more in their crops, and so get higher yields. This benefit of groundwater irrigation helps explain the huge jump in agricultural productivity identified in a recent study by Indian researchers and IWMI. With all these benefits, it is not surprising that farmers and entrepreneurs have invested around US$12 billion in groundwater pump structures. This sum is huge, especially when compared with the US$20 billion of public money spent on surface-water irrigation schemes over the last 50 years.

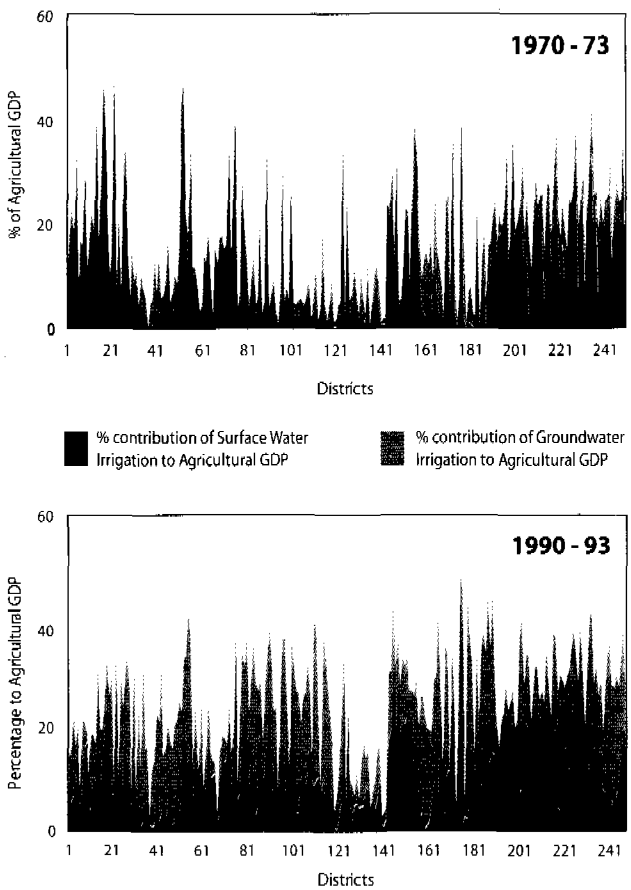
The downside of groundwater use is over-exploitation. In some areas too much groundwater has been extracted, and the effects have been catastrophic. Agriculture has collapsed—destroying people's livelihoods—and drinking water supplies have been endangered with freshwater aquifers becoming polluted. Such disasters happen because groundwater resources are largely unmanaged, and because the policy needed to deal with the problem is not yet in place.

A new finding directly relevant to such policy is that population density and agricultural demand drive

This issue of *Water Policy Briefing* is based on research presented in the paper *Socio-Ecology of Groundwater Irrigation in India* by Aditi Deb Roy and Tushaar Shah. Readers interested in the details of this research are invited to read the full text of the paper at www.iwmi.org/iwmi-tata or request a copy at the address given below. Questions and comments on this issue may be directed to Dr. Tushaar Shah c/o IWMI, Elecon, Anand-Sojitra Road, Vallabh Vidyanagar 388 001, Gujarat, India or iwmi-tata@cgiar.org.

COVER PHOTO: ICRISAT

Figure 1. Change in the contribution of groundwater and surface-water irrigation to agricultural GDP in India



groundwater use—not the quantity of groundwater present or the availability of surface water for groundwater recharge. As the map on page 3 shows some of India's most intensive groundwater irrigation occurs in its most densely populated regions.

What does this imply? Simply that, although everything may look fine on the surface—high groundwater use and booming agriculture—a crash could soon occur because the underlying water resource is insufficient. Resource analysis is needed to tell policy makers how much groundwater can be sustainably tapped in various areas, and to identify hot spots where its use is unsustainable due to lack of reliable recharge.

A newly identified four-stage model of the socio-ecology of India's groundwater use can help policy makers identify appropriate policy intervention points. It describes the 'boom' and 'bust' progression of groundwater development typical of India and South Asia. Tube-well numbers increase (Stage 1) and groundwater based agriculture 'booms' (Stage 2). The first signs of groundwater overuse appear (Stage 3) and the 'boom' turns to 'bust' (Stage 4) as entire areas are plunged into crisis.

Policy is lagging behind the reality of groundwater development. To avoid future crises, policy makers need to update groundwater policies and take steps to:

- **Understand the situation**—recognizing the importance of groundwater to India and the rural poor, and the value of protecting it, and understanding the trends and drivers behind groundwater use;
- **Use resource analysis** to identify hot spots of unsustainable groundwater use and prioritize these for action;
- **Actively manage groundwater**—even in the early stages of the groundwater socio-ecology, shifting from 'resource-development' to 'resource-management' policies *(see box below).*

Policy makers must rise to the challenge of finding ways to manage groundwater sustainably. It is, after all, the most 'democratic' source of water available for improving livelihoods and household food security, and reducing poverty in India's rural areas.

Areas for action: Moving from resource development to resource management

- **Information Systems and Resource Planning:** Functional information systems need to be created, to provide much-needed information about groundwater availability, quality and withdrawal, etc., for use by planners and for the purposes of monitoring and further research.
- **Demand-Side Management:** Systems need to be developed for regulating groundwater withdrawals at sustainable levels. Such mechanisms would include, for example, licences, laws, pricing systems, use of complementary water sources and water-saving crop-production technologies.
- **Supply-Side Management:** Groundwater recharge needs to be augmented, for example, by means of mass rainwater harvesting and recharge activities, the maximization of surface water use for recharge and the introduction of incentives for water conservation and artificial recharge.
- **Groundwater Management in a River Basin Context:** In order to maximize efficiency, the focus of interventions could be expanded (from a very 'local' level to the level of entire river basins).

Groundwater: A new synthesis

After analyzing and evaluating data covering more than 80% of both India's land area and population, recent Indian research has concluded that it's time to take notice of groundwater. In comparison with surface-water irrigation, groundwater irrigation:

- Covers more land and is expanding faster,
- Creates more wealth, and
- Has a greater impact in terms of poverty reduction.

To help us better understand India's fast-changing groundwater situation, the researchers' findings can be easily summarized.

1. The rapid rise of groundwater use

Groundwater use is now so extensive that we can no longer afford to overlook it. Supplying 27 million hectares of farmland, groundwater now irrigates a larger total area than surface water (21 million hectares). This means it sustains almost 60% of the country's irrigated land. On a local level, an increasing number of districts today have larger shares of irrigated land under groundwater irrigation than under surface-water irrigation.

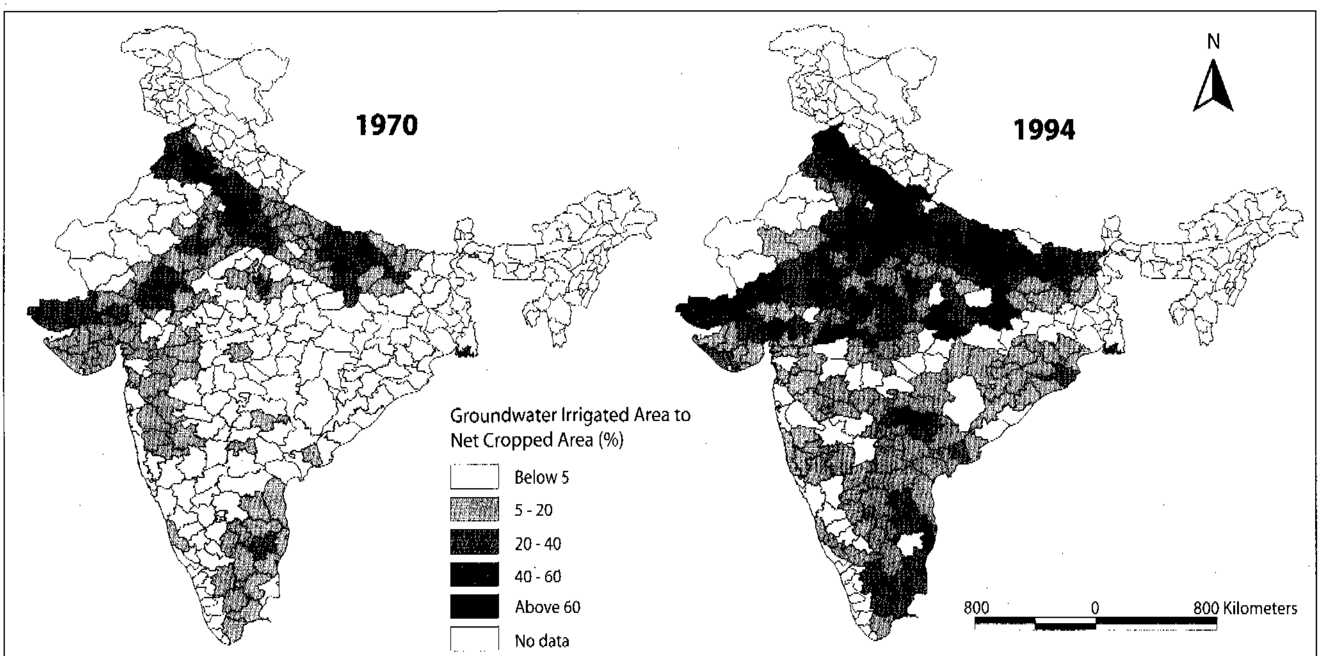
This change in usage in India has been extremely rapid since the 1970s. In just two decades, the groundwater irrigated lands in India have increased by 105%. In contrast, the areas of surface-water irrigated land rose by only 28% over the same period (1970-1994). This change was most striking in northern India—the heart of the Green Revolution *(see Fig. 2 below)*.

A count of mechanized wells and tube wells also illustrates how quickly groundwater irrigation has spread. Numbers of wells have rocketed in the last 40 years, from less than one million in 1960 to more than 19 million in the year 2000. How has this affected agricultural production?

2. Greater wealth from groundwater

Analysis shows that the contribution made by groundwater to the agricultural economy of India has grown steadily since the early 1970s. Groundwater now creates more agricultural wealth than any other irrigation source. In 1993, for example, groundwater use generated Rs 132 billion, while surface water use

Figure 2. Groundwater-irrigated area as a percentage of net cropped area (NCA): 1970 and 1994



District-level population density of India, overlaid with the numbers of groundwater structures fitted with mechanized pumps within those districts. Each dot represents 5,000 energized pumps. The density of energized wells and tube wells corresponds with population density.

In 1970-73 canal water was the main driver of irrigated agriculture. By 1990-93, groundwater became the primary irrigation source

generated only Rs 115 billion. This is a complete reversal from the corresponding values of Rs 21 billion and Rs 77 billion in 1970.

Groundwater-associated agricultural output did not rise at this phenomenal rate simply because the area under groundwater irrigation expanded. Groundwater is actually more productive (producing more crops per hectare) than surface water. This is because farmers who use groundwater can get as much water as they need, when and where they want it. And, knowing that their crops will not fail because of drought, farmers invest more in high-yielding seed varieties, fertilizers and pest control. This leads to higher yields.

What's more, in groundwater irrigation, crop production is higher per unit of water used than it is in surface-water irrigation. This is because it costs farmers money to pump groundwater. So, they use it sparingly and efficiently, timing their irrigation carefully. Research in other countries confirms economic benefits of groundwater irrigation. For example, groundwater is five times more productive than surface water in terms of euros/m^3 in Andalusia (Spain).

Indian researchers have tested a number of hypotheses about groundwater use levels. Analysis of data from 251 districts in 12 major States showed that, between 1970 and 1973, canal irrigation was the main driver of irrigated agriculture. By the 1990-1993 period, groundwater had become the primary force behind irrigation.

Figures for the country as a whole support these findings. Since the 1970s, the contribution of surface water to the total value of agricultural production has fallen by 3%, while that of groundwater has risen by 10%. What's more, this trend has not yet peaked; groundwater use is likely to continue to increase in popularity in the coming decades.

3. Greater impacts in reducing poverty

In relation to the amount of land they cultivate, poor farmers are better represented than richer farmers in their use of groundwater. Small and marginal farms (less than 2 hectares) make up only 29% of the total agricultural area. Yet these small farms account for 38% of the net area irrigated by wells and 35% of the tube wells fitted with electric pump sets. Proportionally more of the large increase we have seen in agricultural outputs—due to groundwater use—goes directly into the stomachs and pockets of the poor.

In fact, groundwater irrigation is inherently less biased against the poor than large dams and large-scale surface water irrigation projects. It creates democratic access to water for all, particularly for small farmers not able to benefit from water in the canal irrigation schemes. For all these reasons, groundwater irrigation is a potentially effective vehicle for poverty eradication. But, without proper management, farmers' need for water for irrigation will destroy the resource which brings them rich agricultural and economic rewards in the short term.

Groundwater overexploitation: Dispelling the myths

There is no doubt that overuse of groundwater occurs, and that it can have devastating effects on communities *(see box on page 5)*. This leads to two burning questions about groundwater overexploitation. Why are some areas affected and not others? How can policy makers predict which are the danger areas? The answers become clear when one key point is understood: groundwater use is dependent on demand, not supply.

Many people think that groundwater is tapped only where it is plentiful, where there are large aquifers, or a lot of rainfall or surface irrigation systems—which result in water trickling down through the soil to recharge underground supplies. Although these 'supply-push' factors may have been important in the past, research shows the 'demand-pull' of farmers' irrigation needs is now far more important.

1. Demand determines groundwater use

Recent research analyzed macro-level data from the early 1990s in an innovative way. Models showed that population density and agricultural productivity (both demand-pull factors) had the greatest positive association with groundwater pump density in the 225 districts studied. Similar conclusions were drawn from extensive research in the Pakistan Punjab, which showed that groundwater is tapped where people are, not necessarily where groundwater is abundant.

Groundwater is tapped where people are, not necessarily where it is abundant

2. Groundwater does not depend on surface-water irrigation

It is popularly believed that groundwater use is intensive in areas of surface-water irrigation, and that it is mostly the seepage from canals that is extracted by the millions of private groundwater pump owners.

New research shows that between the early 1970s and the early 1990s, groundwater irrigation developed independently of the expansion of surface-water irrigation. By the 1990s, groundwater irrigation had increased dramatically in areas where there was actually very little surface water available. Groundwater irrigation does not occur in concentrated pockets only where there are surface-water schemes. It was really the spread of the Green Revolution that caused groundwater structures to 'mushroom' across the length and breadth of the country.

The four stages of groundwater socio-ecology

	Stage 1	Stage 2	Stage 3	Stage 4
Stages	**Rise in the Use of Tube-well Technologies**	**Groundwater-Based Agrarian Boom**	**Early Symptoms of Groundwater Overexploitation**	**Agricultural Decline and Crisis**
Examples	North Bengal, North Bihar, Nepal Terai, Orissa	Eastern Uttar Pradesh, Western Godavari, Central and South Gujarat	Haryana, Punjab, Western Uttar Pradesh, Central Tamil Nadu	North Gujarat, Tamil Nadu, Saurashtra, Southern Rajasthan
Characteristics	Subsistence agriculture; protective irrigation; traditional crops; concentrated rural poverty; traditional water-lifting devices (human and animal-powered).	Tube-well ownership skewed; access to pump irrigation prized; rise of primitive pump irrigation 'exchange' institutions; traditional water-lifting technologies decline; rapid growth in agrarian income and employment.	Crop diversification; permanent decline in water tables; groundwater-based 'bubble economy' continues to boom, but tensions between economy and ecology surface as pumping costs soar and water market becomes oppressive; private and social costs of ground-water use diverge.	Groundwater-based 'bubble' bursts; agricultural growth declines; the poor become poorer and there is depopulation of entire clusters of villages; water-quality problems assume serious proportions; the 'smart' begin to move out long before the crisis deepens; the poor are hit the hardest.
Interventions	Targeted subsidies for pump capital; public tube-well programs; electricity subsidies and flat tariffs.	Subsidies continue; institutional credit available for wells and pumps; donors augment resources for pump capital; NGOs promote small farmer irrigation as a livelihood program.	Subsidies, credit, and donor and NGO support continue apace; licensing, siting norms and zoning system are created but are weakly enforced. Groundwater irrigators emerge as a huge, powerful vote-bank that political leaders cannot ignore.	Subsidies, credit and donor-support reluctantly end; NGOs and donors assume a conservationist stance; zoning restrictions begin to be enforced, with frequent preelection relaxations; water imports begin for domestic needs; numerous public and NGO-sponsored actions are implemented to ameliorate problems of this stage.

3. Groundwater use does not depend on its availability

Analysis of data for 225 districts showed that by the 1990s, the use of groundwater was not related to the availability of the resource. In fact, between the 1970s and the 1990s, the number of districts using high levels of groundwater—even though they had limited reserves of the resource—increased dramatically. These districts were mostly located in western and northern India. It is in districts like these—where there is high demand but low supply—that over-exploitation is most likely to occur.

Consequences of overexploiting groundwater

Declining groundwater levels cause huge environmental, social and economic costs because of four main factors:

- The salinization of aquifers (due to seawater intrusion), which affects drinking water and crops
- The pollution of aquifers (e.g., by arsenic and chromium) which affects drinking water and crops and has serious health consequences
- Increased costs of pumping
- The abandonment of wells (from which water can no longer be pumped)

Groundwater depletion is highest in western India. There, half of the wells once in use are now out of commission. This figure will increase as water tables decline. In fact, if the number of overexploited 'blocks' continues to grow at the present rate of 5.5% per annum, by 2018 roughly 36% of India's blocks will face serious problems.

> Tamil Nadu, North Gujarat, and majority districts of Punjab and Haryana rely heavily on groundwater, but have limited stocks of the resource

This illustrates the very real danger associated with demand-driven exploitation of water resources: groundwater is being tapped in areas where it should not be. Tamil Nadu, the whole of North Gujarat and the majority of the districts in Punjab and Haryana are all areas that rely heavily on groundwater, but have limited stocks of the resource. These are all examples of areas where appropriate policy interventions now could avoid problems in the future.

Targeting policies—when and where?

The research highlighted here and other studies has shown that, in much of South Asia, the rise and fall of local groundwater economies follows a four-stage progression. Using this model, we can predict two things. First, unutilized groundwater resources will trigger agrarian 'booms' when first developed. Second, if controls are not quickly applied, a region will overexploit its groundwater and be hard hit by the resulting crisis. Unfortunately, this drama has been re-enacted with frightening regularity.

In Stage 1 and the early phases of Stage 2, of the model, effective policies promote the profitable use of this valuable, renewable resource for generating wealth and economic surplus. But, even at Stage 2, thinking should turn towards careful resources management. This will prevent the considerable socioeconomic and ecological problems associated with Stages 3 and 4.

In South Asian countries, vast regions have already entered Stages 3 and 4. Unfortunately, they are still applying policies ideal for use in Stages 1 and 2. Lack of policy change worsens the problems associated with the later stages of this socio-ecological model. Eventually, it necessitates the introduction of a whole suite of new policies and investments needed to 'clean up the mess.'

The frontline challenge is to introduce corrective mechanisms before the problem becomes either unsolvable or not worth solving. In other words, Indian policy makers and natural resource planners need to make a transition from a resource *development* to a resource *management* mind-set.

Water Policy Briefing Series

The Water Policy Briefing Series translates the findings of research in water resources management into useful information for Indian policy makers. The Series is put out by the International Water Management Institute (IWMI) in collaboration with national and State research organizations. It is made possible by a grant from the Sir Ratan Tata Trust.

Each Briefing is supported by detailed research documentation, available on the Institute's website **(www.iwmi.org/iwmi-tata)** or by direct request (iwmi-tata@cgiar.org).

The editors of the Series welcome comments and questions. Please send correspondence to:

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IWMI-Tata Water Policy Program

The IWMI-Tata Water Policy Program was launched in 2000. This is a new initiative supported by the Sir Ratan Tata Trust. The program presents new perspectives and practical solutions derived from the wealth of research done in India on water resources management. Its objective is to help policy makers at the central, State and local levels address their water challenges—in areas such as sustainable groundwater management, water scarcity, and rural poverty—by translating research findings into practical policy recommendations.

Through this program, IWMI collaborates with a range of partners across India to identify, analyze and document relevant water-management approaches and current practices. These practices are assessed and synthesized for maximum policy impact in the *Water Policy Briefing* Series.

The Policy Program's website **(www.iwmi.org/iwmi-tata)** promotes the exchange of knowledge on water-resources management, within the research community and between researchers and policy makers in India.

IWMI in India

Over the past decade, researchers from IWMI have been collaborating with Indian scientists and development organizations in the areas of irrigation performance; satellite remote sensing; irrigation management transfer; analysis of gender, water and poverty; and malaria control.

In January 2001, a field office was established in Anand, Gujarat to work with Indian partners on groundwater management and governance. In October 2001, IWMI established its India Regional Office in Patancheru, Hyderabad, Andhra Pradesh. IWMI's research and cooperation in India focus on three key areas: river basin water productivity, water and land management in watersheds, and groundwater management.

IWMI's principal partners and collaborators for its work in India are the Indian Council of Agricultural Research (ICAR), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and a host of state irrigation departments, agricultural universities and nongovernmental organizations.

For further information, see **www.iwmi.org/india** or write to iwmi-india@cgiar.org

About IWMI

IWMI is one of the 16 Future Harvest Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

The research program of IWMI centers around five core themes:

- Integrated Water Resources Management for Agriculture
- Sustainable Smallholder Water & Land Management Systems
- Sustainable Groundwater Management
- Water, Health and Environment
- Water Resources Institutions and Policy

The Institute fields a team of some 50 senior researchers with significant international experience, supported by national research staff and a corps of some 20 postdoctoral scientists, mostly from developing countries. IWMI is headquartered in Sri Lanka with regional offices in India, South Africa and Thailand.

All IWMI research is done with local partners (universities, government agencies, NGOs, research centers, etc.). The Institute's outputs are public goods that are freely available for use by all actors in water management and development. The IWMI Research Reports, data and other publications can be downloaded from the IWMI website or received free of charge from the IWMI publications office. A series of tools for improved water management is also available.

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