WATER POLICY BRIEF

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Putting Research Knowledge into Action

Banking on Groundwater
in Times of Change

Climate and other drivers of change raise questions about the continued reliance on surface water resources, prompting countries to fundamentally rethink groundwater management strategies.

Key findings

- A range of technical options are available for groundwater recharge. Technology aside, a managed recharge strategy strongly implies a shift to conjunctive management of surface water and groundwater.
- Groundwater storage offers a number of unique benefits, including potentially wider, more reliable and equitable access.
- Groundwater storage – whether it is underused or overexploited – creates opportunities for adaptation to, and mitigation of, climate change and offers attractive and innovative solutions to complex water allocation problems.

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In the 1960s there was a Green Revolution. It was powered by high-yielding seed varieties, chemical fertilizers and mass irrigation schemes. In the early 1970s, a second, much quieter revolution began picking up force, this one powered by the widespread availability of cheap diesel and electric pumps. Groundwater now accounts for approximately 50% of all irrigation water supply in South Asia and perhaps two-thirds in the grain belts of North China. Statistics on groundwater use are much harder to come by in Africa, but indications are that groundwater use is picking up. There are, for example, an estimated 35,000 borehole wells being used for domestic water and irrigation in Limpopo Province in South Africa, and water supply in Botswana is largely from groundwater.

Farmers in Jharkhand State, India tap into local electricity lines to power their pumps.

The rising tide of groundwater use has lifted millions of small farmers out of poverty, but there are significant risks that come with increased use. Where farmers in South Asia have turned to groundwater as a primary source of water for irrigation, economies follow a typical pattern of agrarian boom followed by overextraction, depletion and degradation. Areas like Eastern Uttar Pradesh and South Gujarat are in the boom stage, Haryana and Punjab are showing signs of overdraft, and coastal areas like Tamil Nadu and southern Rajasthan are in decline. Other parts of the world display different patterns. In sub-Saharan Africa and Central America, much of the potential of groundwater remains locked in the ground due to a range of technical, socioeconomic and policy barriers.

Where groundwater is extensively used, some of the common problems are groundwater pollution and competition for use, mainly from cities and for hydropower. There is also the link to climate. Increasing rainfall variability worldwide stimulates even more use of groundwater, while at the same time altering the rate of recharge. Pumping groundwater also contributes to greenhouse gas emissions. For example, emissions from an estimated 19 million diesel pumps make up approximately 6% of India's total greenhouse gas emissions.

Facing climate change: How India is seizing the opportunity

India has led the groundwater revolution from the beginning, and is the biggest user of groundwater among all the world's nations. Over the last century, groundwater has evolved from a fallback strategy in times of drought to the mainstay of India's current agricultural economy. Climate change alters India's hydro-climatic regime, encouraging even more use of groundwater.

It is in India that the pattern of agricultural groundwater boom and bust is most prominent. In regions like North Gujarat and the large coastal aquifers of Tamil Nadu, Saurashtra and Rajasthan, overextraction led to the collapse of agricultural economies, followed by a host of government and non-governmental organization (NGO) intervention strategies focused on conservation, water imports and 'alternative livelihood' strategies; none of which have replaced the benefits conferred by groundwater.

Groundwater depletion is a serious concern. However, with a slight change of mindset, groundwater extraction becomes an opportunity because it creates storage capacity. In a warming climate, one of the best places to store water is underground where it is shielded from high rates of evaporation and where it is accessible to large numbers of small farmers when and where they need it.

Groundwater storage capacity is only an opportunity if there is a coherent strategy for managed aquifer recharge. Such a strategy must be proactive and be supported by regional and national policies appropriate to the socioeconomic and hydrogeological context of the region. In India, for example, without demand- and supply-side management of the pump irrigation economies, groundwater levels in most aquifers display behavior characterized in Figure 1a. In the initial years, water level fluctuations before and after monsoon rains become more amplified. As pre-monsoon water levels drop considerably below the vadose zone, natural recharge rates decline and the pumping head increases rapidly. This is the pattern that bursts the agricultural bubble supported by groundwater irrigation. With changing climate, associated with shorter monsoons and higher evaporation rates, this trend is becoming even more alarming.

With proactive demand- and supply-side management, the desired situation is shown in Figure 1b. With groundwater development, fluctuations will amplify; but as long as rainfall is managed to recharge aquifers, and proactive water saving strategies are put in place, a steady, sustainable state can be achieved.

Groundwater irrigation has become common across India. Farmer family with a well.

A range of technical options are available for managing groundwater recharge. Direct surface methods are among the most widely used and simplest. Depending on local conditions, water is simply spread over fields to percolate into shallow aquifers. Other methods include digging flooding pits or shafts; or 'injecting' water into aquifers

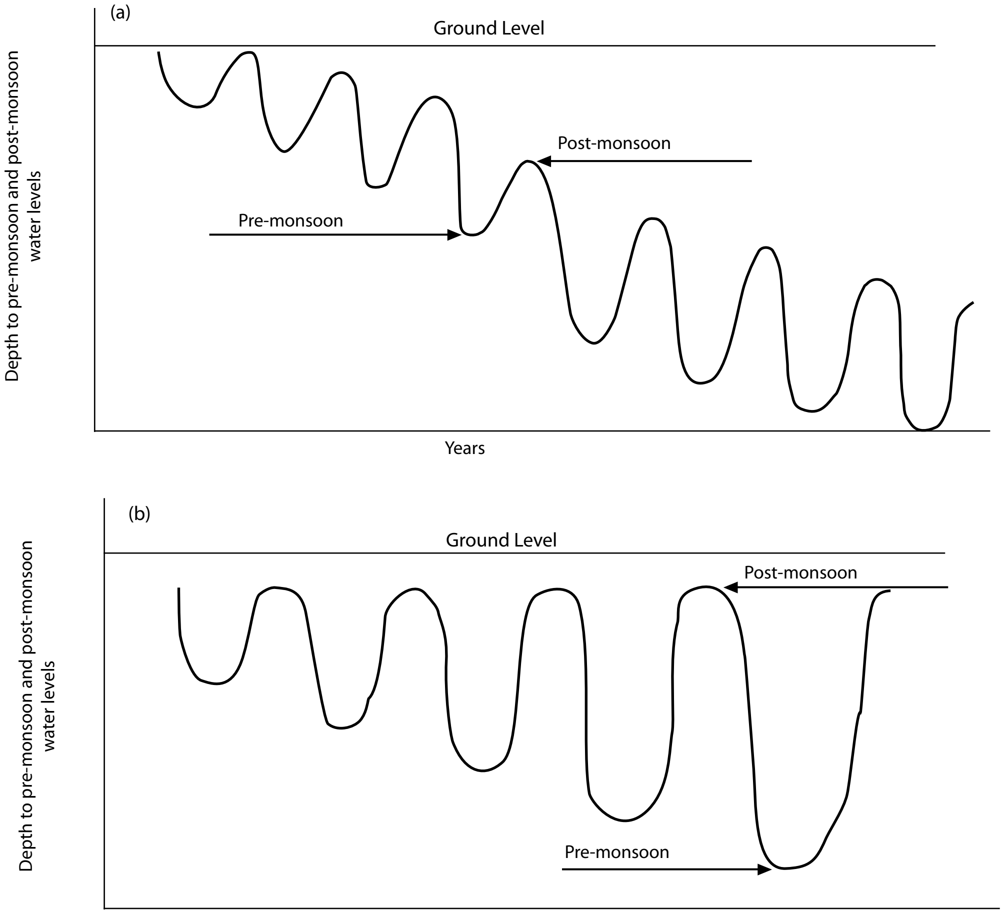

Figure 1: a) Groundwater level decline without managed recharge; and b) with managed recharge programme.

through deep boreholes or tube wells from surface water bodies. Groundwater recharge is often best accomplished as a by-product of integrated or 'conjunctive' management of reservoir and canal seepage, injection and infiltration of return flow from irrigation, enhanced infiltration of rainfall, or the simple leveling of fields or construction of small check dams. Technology aside, a managed recharge strategy strongly implies a shift to comanagement of surface water and groundwater. These interactions are well understood in the scientific domain, but remain almost entirely separate domains in the day-to-day worlds of policy and water management authorities.

Groundwater storage offers a number of unique benefits, including potentially wider, more equitable access. Groundwater (as long as there is a source of it) is accessible to anyone with the means to dig a well; an attractive option where surface water management is often highly politicized. As a climate change adaptation measure, aquifers respond to droughts and climate fluctuations much more slowly than surface storage structures, and are more resilient buffers during dry spells.

The analysis shows four possible storage alternatives, in this case for countries such as India (Table 1). The analysis assigns up to five benefits or five disbenefits to each of 12 criteria. The first two options, small surface storage facilities and large surface reservoirs are quite well known. The third option, aquifer storage, represents the groundwater boom India has experienced, in which mostly shallow aquifer storage has been relentlessly exploited through individual action by millions of small farmers without any demand-side management or systematic strategy of enhancing aquifer recharge. The fourth option, managed aquifer storage, does not exist yet, and will require a radical shift in thinking. It recognizes that groundwater demand will increase, but, depending on a region's hydrology, aquifer storage can sustain this increase with proactive demand-side management and a region-wide program of managed aquifer recharge.

Solving transboundary issues in Fergana Valley, Central Asia: When second best is best

The Fergana Valley in Central Asia presents an entirely different context; one where groundwater may be the solution to an entirely different sort of problem. Here, the source of irrigation water supply has depended almost entirely on tightly regulated surface water storage facilities. During the 1970s and 1980s, certain segments of the agriculture sector gained huge benefits from the increased production of cotton, wheat and other crops that massive command-style irrigation schemes can provide. It was not long however, before all the conventional problems that go with large-scale surface irrigation became apparent – waterlogging, soil salinization, environmental problems resulting from wide-scale water diversions, the Aral Sea disaster being a prime example.

Table 1: Climate change and water storage alternatives.

	Small surface storage	Large surface reservoirs	Aquifer storage (BAU)	Managed aquifer storage
1. Make water available where needed (space utility)	↑↑↑	↑↑	↑↑↑↑	↑↑↑↑↑
2. Make water available when needed (time utility)	↑	↑↑	↑↑↑↑	↑↑↑↑↑
3. Level of water control offered (from utility)	↑	↑↑	↑↑↑↑	↑↑↑↑↑
4. Non-beneficial evaporation from storage	↓↓↓↓	↓↓	↓	↓
5. Non-beneficial evaporation from transport	↓↓	↓↓↓	↓	↓
6. Protection against mid-monsoon dry spell (2-8 weeks)	↑↑	↑↑↑	↑↑↑↑↑	↑↑↑↑↑
7. Protection against a single annual drought	↑	↑	↑↑↑	↑↑↑↑↑
8. Protection against two successive annual drought	↑	↑	↑↑	↑↑↑↑
9. Ease of storage recovery during a good monsoon	↑↑↑↑↑	↑↑↑↑	↑↑	↑↑↑
10. Social capital cost of water storage and transport and retrieval structure	↓↓	↓↓↓↓↓	↓↓	↓↓↓
11. Operation and maintenance social costs of storage, transport and retrieval structures	↓	↓↓	↓↓↓↓↓	↓↓↓
12. Carbon footprint of agricultural water use	↓	↓↓	↓↓↓↓↓	↓↓↓

Since the end of the Soviet Regime, conflicts between different users, mainly irrigation and hydropower, have emerged as contentious political issues between upstream Kyrgyzstan and its downstream neighbors, Uzbekistan and Kazakhstan.

The Syr Darya River Basin (Figure 2), now a transboundary basin spanning Kyrgyzstan, Tajikistan, Uzbekistan and Kazakhstan, witnessed extensive large-scale irrigation development in the 1960s. Diversion of water from the Syr Darya and a similar development in the Amu Darya River was largely responsible for drying up of the Aral Sea. During this period, a series of multipurpose dams were constructed to regulate flows and ensure summer irrigation supplies. Among these is the Toktogul Reservoir (14,000 million cubic meters (Mm^3)) on the Naryn River in what is now Kyrgyzstan. The Toktogul Reservoir was designed for both irrigation and hydropower, principally to ensure supplies to the middle stretch of the Syr Darya River. Since independence in 1991, the existing water management and allocation arrangements have been substantially modified by Kyrgyzstan's decision to operate their dams for winter hydropower generation.

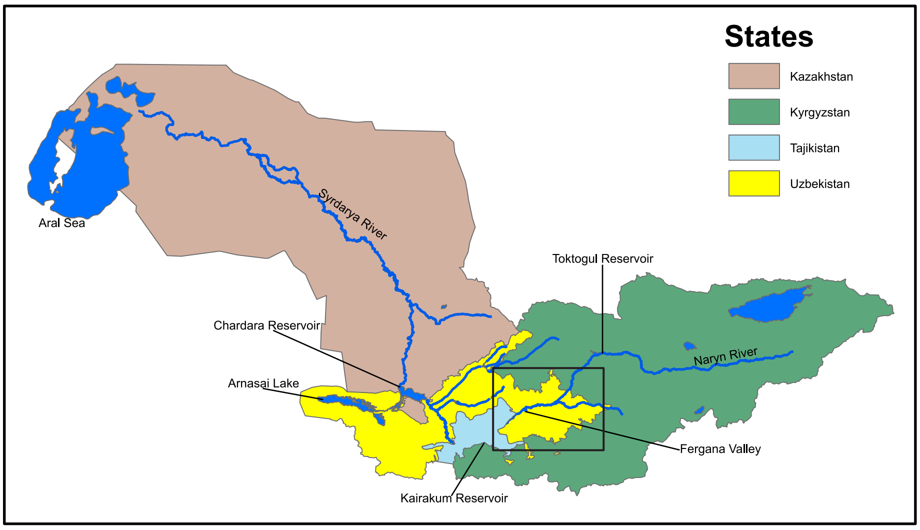

Figure 2: The map of Syr Darya River Basin.

The most significant impact of this decision in terms of agriculture has been increased winter river flows and lower water availability in the summer in the downstream stretches of the river where water is required for irrigation during this period. More significantly, the downstream stretch of the Syr Darya River does not have sufficient capacity to pass excessive winter flows that are now nearly twice as large as they were before 1992. As a result, winter flows are diverted into the nearby Arnasai depression, forming an artificial lake that currently holds some 40,000 Mm^3 of increasingly saline water.

A negotiated political resolution to a more equitable water sharing regime is not expected soon. In the meantime, a managed groundwater recharge program offers a practical, 'second best' solution. Rather than allow the problem to grow in the form of an increasingly large and saline water body of little use to agriculture, downstream farmers could switch from using surface water to using groundwater for their summer irrigation needs, and use the winter runoff to recharge the aquifers for the next growing season. Glacier and snowmelt are significant factors in the hydrological regime in Central Asia. Although the impacts of climate change remain uncertain at present, it is likely that glacier and snow storages will decrease in the future, which will increase flow variability in the long run. Hence, it is necessary to look for additional storage alternatives now - to capture more variable flows in the future.

The first step has already been taken: an assessment of the feasibility of banking excess surface flows in aquifers in winter and increasing groundwater use for irrigation purposes in summer to compensate for lower surface flows and to provide storage capacity for groundwater recharge. A water balance study was conducted by the Hydrogeology and Engineering Geology Research Institute (GIDROINGEO) in Tashkent and the International Water Management Institute (IWMI) in Sri Lanka. The study was conducted for the whole of the Fergana Valley, incorporating 18 aquifers, based on geographic information systems (GIS) analysis of

Comanagement of surface water and groundwater offers attractive and innovative solutions to complex, politicized water allocation problems.

the water balance in 1995 and 2001. It helped that there was a comprehensive set of data based on extensive monitoring from Soviet times.

Current groundwater storage available for recharge exceeds 3,000 Mm^3. More capacity could be created by groundwater abstraction at the rate of 186 Mm^3 for each meter of water table drawdown. These figures show that there is sufficient capacity to store winter hydropower releases. Areas for managed aquifer recharge are spread out throughout the Fergana Valley (Figure 3). However, methods for recharging individual aquifers based on local hydrological conditions have yet to be developed.

The Syr Darya study presents a concrete and quantified example of how comanagement of surface water and groundwater offers attractive and innovative solutions to complex, politicized water allocation problems. Nevertheless, a good deal more work is required, especially on the economics and the institutional and operational aspects of implementing such a strategy. In the long-term, climate change impacts on the snowpack in the source areas will further modify the release patterns and flows in this complex system. Such changes ultimately need to be incorporated into surface water-groundwater management strategies, but the tools and approaches to do so are emerging.

Conclusion

In mainstream irrigation thinking, groundwater recharge is viewed as a by-product of flow irrigation, but in today's world, this equation needs to be stood on its head. With climate change, storage will be vital, especially for irrigation. The big hope for surface irrigation systems in many parts of the world maybe to reinvent them. Investments in relatively inexpensive engineering would be needed to enhance and stabilize groundwater aquifers that offer water supply close to points of use, permitting frequent and flexible just-in- time irrigation of diverse crops. Already, many canal irrigation systems create value, not through flow irrigation but by supporting groundwater irrigation by default through farmers' investments in tube wells in command areas. Increasingly, in many regions surface storage makes economic sense only for sustaining on-demand groundwater irrigation in extended command areas.

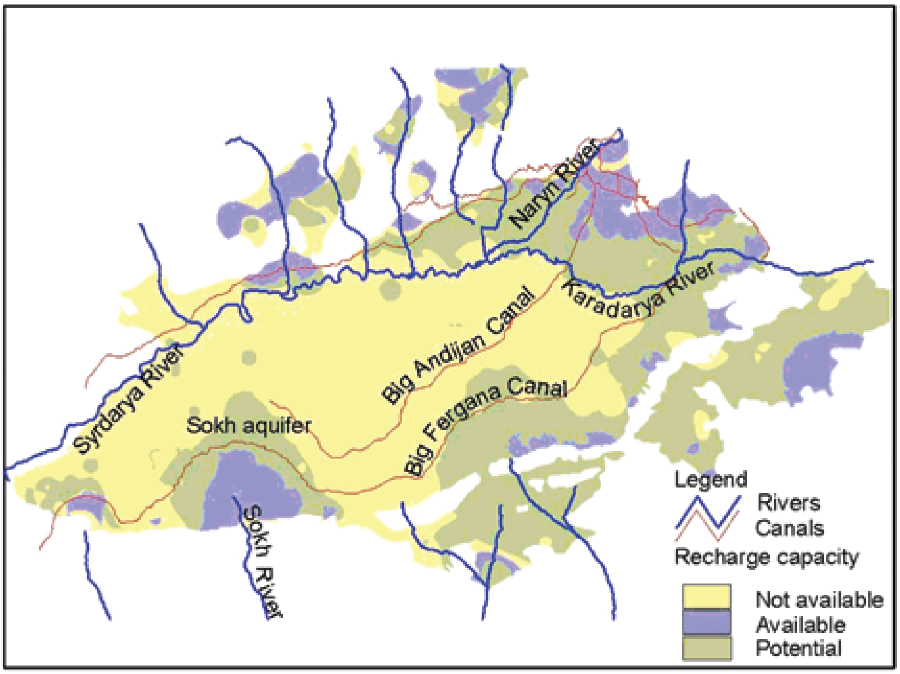

Figure 3: Zones with potential for water banking in the Fergana Valley.

Groundwater irrigation triggered an agricultural boom in Gujarat, India.

Groundwater irrigation in regions like Central Asia means farmers can plan their cropping patterns from year to year.

Source

This issue of Water Policy Brief is based on research conducted by Tushaar Shah and Akmal Karimov, with partner organizations.

The content is also based on the following externally peer-reviewed publications:

Gracheva, I.; Karimov, A.; Turral, H.; Miryusupov, F. 2009. An assessment of the potential and impacts of winter water banking in the Sokh aquifer, Central Asia. Hydrogeology Journal 17(6): 1471-1482.

Karimov, A.; Mavlonov, A.; Smakhtin, V.; Turral, H.; Gracheva, I. 2009. Groundwater development in Fergana Valley: the adaptation strategy for changed water management in the Syrdarya Basin. In: Improving integrated surface and groundwater resources management in a vulnerable and changing world. Proceedings of the JS.3 at the joint IAHS and IAH Convention, Hyderabad, India, September, 2009. IAHS Publication 330, 2009. Pp. 22-27.

Shah, T. 2009. Climate change and groundwater: India's opportunities for mitigation and adaptation. Environmental Research Letters 4 (035005). 13p.

Other Related IWMI Publications

Open access (electronic version freely accessible via the internet)

Giordano, M.; Villholth, K. G. (eds.). 2007. The agricultural groundwater revolution: opportunities and threats to development. Wallingford, UK: CABI. 419p. (Comprehensive Assessment of Water Management in Agriculture Series 3).

IWMI (International Water Management Institute). 2006. Improving performance and financial viability of irrigation systems in India and China. Colombo, Sri Lanka: International Water Management Institute. 6p. (IWMI Water Policy Briefing 20).

IWMI (International Water Management Institute). 2009. Water Storage and Climate Change. Water Figures: quarterly newsletter of the International Water Management Institute (IWMI). 2. 8p.

IWMI (International Water Management Institute). 2009. Flexible water storage options and adaptation to climate change. Colombo, Sri Lanka: International Water Management Institute (IWMI). 8p. (IWMI Water Policy Brief 31).

Non-open access

Mukherji, A.; Villholth, K. G.; Sharma, B. R.; Wang, J. (eds.). 2009. Groundwater governance in the Indo-Gangetic and Yellow River basins: realities and challenges. London, UK: CRC Press. 325p. (IAH Selected Papers on Hydrogeology 15).

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