10 The Groundwater Recharge Movement in India

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Introduction

The easy accessibility of groundwater by even small-scale users, its local availability and the difficulty of coordinating and governing many users of the same aquifers across wide geographic spaces has frequently led to indiscriminate extraction of this precious natural resource for domestic, industrial and agricultural uses around the world. Groundwater exploitation, particularly in India, has increased by leaps and bounds over the last 50 years along with the expansion of shallow, mostly private, wells. The growth of groundwater abstraction structures from 1950 to 1990 clearly depicts the increasing use of groundwater utilization across sectors. As per available published statistics, the number of dug wells increased from 3.86 million (1951) to 9.49 million (1990) and of shallow tube wells from 3000 (1951) to 4.75 million (1990) (Muralidharan and Athavale, 1998). Shah (Chapter 2, this volume) highlights that these trends continue to the present.

The reasons for the increase in groundwater use in India are varied and include technological, hydrologic and policy factors. Technologically, developments over the last 50 years in the construction of deep tube wells, water abstraction devices and pumping methods have made large-scale exploitation of groundwater both possible and economic. At the same time, changes in hydrologic regimes, in particular the growing scarcity of surface water supplies as agricultural and other users have expanded, have pushed water users to seek groundwater alternatives. Finally, government policy has tended to support groundwater use. Easy availability of credit from financial institutions for sinking tube wells coupled with the provision of subsidized or free electricity (see Shah *et al.*, Chapter 11, this volume) for pumping in many states has encouraged increased extraction.

As demand for groundwater has gone up, rapid urbanization and land use changes have decreased drastically the already low infiltration rates of rainfall into the soil and have diminished the natural recharging of aquifers. Natural recharge measurements carried out in about 20 river basins across India suggest that about 15–20% of seasonal rainfall contributes to groundwater recharge in the Indo-Gangetic plains, figures that fall to only 5–10% in the peninsular hard-rock regions (Athavale *et al.*, 1992).

Increased use and limited recharge have contributed to the lowering of the water table so much that yields of many dug and tube wells have decreased substantially or even fallen to zero, particularly during the summer. The drinking water crisis that ensues in many villages in summer imposes serious health hazards to the rural masses and is responsible for the huge loss of livestock populations for want of drinking water and fodder (Shah, 1998). The general implications for agriculture are no less severe.

To respond to the growing groundwater crisis and take advantage of the high levels of runoff not captured by natural recharge, augmentation of groundwater resources through artificial recharge of aquifers has become widespread in India over the last 3–4 decades. In fact, the growth in the use of artificial recharge has expanded to such an extent that it can be called a 'groundwater recharge movement', which has behind it both secular and spiritual proponents. This recent movement builds on artificial groundwater recharge concepts that have been practised from time immemorial in the hard-rock, semi-arid regions of south- and north-western India.

In some senses, the artificial recharge movement in India can be considered as a successful example of community-based efforts to manage common property resources. However, because of the distributed nature of aquifers and their interconnectivity across space and with surface water supplies, recharge by one group or community may impact water availability for other neighbouring or downstream groups. Thus, the artificial recharge movement in India highlights both the benefits and problems of community-based approaches highlighted by Schlager (Chapter 7, this volume).

This chapter looks at the historical evolution of the groundwater recharge movement in India, how it has gathered momentum, who has been responsible for it and what it has achieved to date. Through two contrasting case studies, it then highlights both the clear local benefits of artificial recharge and the potential for negative impacts at larger scales. Together these studies show the potential gains and the governance problems that will necessarily follow the artificial recharge movement as it continues to move forward in India. The studies also provide some guidance in how artificial recharge can, and cannot, be used to solve groundwater problems.

The Artificial Recharge Movement in India

Artificial recharge, one of the oldest activities undertaken in India to conserve rainwater both above-ground and underground, is as old as the irrigated agriculture in the arid and semi-arid regions. In the olden days, the recharge movement initiated by the local communities was aided and supported by kings, chieftains, philanthropists and by those who valued water and practised conservation. There are numerous examples and stone inscriptions from as early as AD 600, citing that ancient kings and other benevolent persons considered as one of their bound duties the construction of *ooranies* (ponds) to collect rainwater and use it to recharge wells constructed within or outside *ooranies* to serve as drinking water source. Even today, thousands of such structures exist and are in use for multiple purposes in the southern coastal towns and villages of Tamil Nadu where groundwater is saline (DHAN Fondation, 2002).

Similarly, more than 500,000 tanks and ponds, big and small, are dotted all over the country, particularly in peninsular India. These tanks were constructed thousands of years ago for catering to the multiple uses of irrigated agriculture, livestock and human uses such as drinking, bathing and washing. The command area of these tanks has numerous shallow dug wells that are recharged with tank water and accessed to augment surface supplies. Many drinking water wells located within the tank bed and/or on the tank bund are artificially recharged from the tank into these wells to provide clean water supply throughout the year with natural filtering (DHAN Foundation, 2002).

In traditionally managed tank irrigation systems, when gravity-supplied water from the tank is insufficient for crop production, it is not uncommon that the village community decides to close all the tank sluices and allow the tank to act as a percolation unit to recharge the wells in the command area; the recharged water is then shared by the beneficiary farmers. This has been done to distribute the limited water to the crops without any line losses due to gravity flow. This practice is in use even today in many traditionally managed irrigation systems. However, with water supply to many tanks dwindling, converting irrigation tanks to purely percolation tanks for artificial recharge of wells in the command is increasing day by day. The trend has essentially become a movement by itself and even some state governments such as Karnataka are encouraging the practice through enactment of law enforcement (Sakthivadivel and Gomathinayagam, 2004).

Rooftop rainwater harvesting and the storage of harvested water in underground tanks is also a very common phenomenon in many Indian states experiencing acute shortage of drinking water supplies. Similarly, pumping induced recharge water from wells located near water storage structures like tanks, irrigation canals and river courses, and transporting it to a long distance through pipelines for irrigation is a common sight in many water-deficient basins. These activities can also be considered a social movement that originated spontaneously from local necessity. Further details on traditional water harvesting and recharge structures can be found in *Dying Wisdom* (Agrawal and Narain, 2001).

Progression of the Artificial Recharge Movement

The spread of the artificial recharge movement in India (ARMI) can be broadly classified under three phases: the first relates to the period before the Green Revolution when limited exploitation of groundwater was taking place, i.e. before 1960; the second is the period between 1960 and 1990 in which intense groundwater exploitation took place, leading to signs of overexploitation;

and the third is the period from 1990 to date when water scarcity became increasingly severe, and groundwater level decline became alarming in many pockets of the country.

In the first phase, which extended from early historic times until approximately 1960, traditional water-harvesting methods were given impetus through unorganized yet spontaneous movement by the local communities aided by kings and benevolent persons to meet the local requirement at times of crisis. During this period, there was very little knowledge-based input from the government or other organizations to provide assistance for understanding and systematically putting into practice artificial recharging. Instead, local communities used their intimate knowledge of terrain, topography and hydrogeology of their areas to construct and operate successful artificial recharge structures, some of which have managed to survive even today. In this phase, there was little application of science related to artificial recharging; most work was based on local knowledge and perceived wisdom. Very little understanding existed about the consequences of, and the knowledge required for, artificial recharging of underground aquifers.

The second phase, from 1960 to 1990, coincides with the period of large-scale extraction of groundwater that resulted in many aquifer systems showing signs of overexploitation, especially in arid and semi-arid regions. During this phase, curriculum relating to hydrogeology and groundwater engineering was introduced in many universities in India and the science of groundwater hydrology was better understood. Both the public and government had started realizing the importance of recharging aquifers to arrest groundwater decline and maintain groundwater levels. As a consequence, pilot studies of artificial recharge of aquifers were carried out by a number of agencies including central and state groundwater boards, water supply and drainage boards, research institutes such as National Geophysical Research Institute (NGRI), Physical Research Laboratory (PRL), National Environmental Engineering Research Institute (NEERI), agricultural and other academic institutions, and non-governmental organizations (NGOs) such as the Centre for Science and Environment (CSE).

During this period, various pilot studies were carried out and technical feasibility of artificial recharging and recovery of recharged water were established. Two important events with respect to artificial recharge also took place that are of relevance to the movement today. One is the synthesis of research and development works (Mission WatSan, 1997) carried out in India in artificial recharging by a team of experts under the Rajiv Gandhi National Drinking Water Mission (RGNDWM), constituted by the Ministry of Rural Areas and Development, Government of India, New Delhi. The second is the effort provided by the Bureau of Indian Standards (BIS) to bring out technical guidelines and specifications for artificial recharging. These have given impetus for further experimentation on artificial recharging.

In the third current phase, from 1990 to the present, water scarcity, continuous droughts in certain pockets of India and continuously declining groundwater levels in many parts of India have led both the public and government to become more aware of artificial recharge and to take it up on a war footing. Four major events that have taken place during this period are especially significant to the movement. One is the spontaneous uprising and cooperation from the public supported by religious leaders, philanthropists and committed individuals to take up artificial recharging through dug and bore wells, check dams and percolation ponds and, later – with the government joining hands with the local community – in implementing such schemes on a mass scale (Shah, 1998). The second is the action taken by state governments such as Tamil Nadu in promulgating the groundwater regulation acts pertaining to metropolitan areas and ordering the communities to implement rainwater-harvesting schemes and artificial recharging on a compulsory basis. The third event relates to awareness created among the public by NGOs such as the CSE and Tarun Bharat Sangh (TBS), and media exposure to the importance of artificial recharging.

The fourth event is the recently increasing trend of large-scale abstraction of induced recharge witnessed in many gravity irrigation systems in states like Tamil Nadu. With increasing water scarcity in many irrigation systems and availability of large-scale pumping machinery at affordable prices and subsidized power, many enterprising farmers have turned to wells near storage reservoirs, and on the sides of canals and riverine courses to create induced recharge in their own wells. The induced recharge water is transported through pipelines sometimes many kilometres away from the pumping site to irrigate non-command areas of orchards and other high-value crops, often using drip and sprinkler irrigation. This practice of pumping-induced recharge water outside the command area has had a very negative effect in managing large irrigation systems due to the siphoning of a considerable quantity of water to areas not originally included in the command. This is more so in years of inadequate water supplies to reservoirs as well as in drought years. This is a spontaneous movement, which is spreading like wildfire; if it is not controlled and regulated, many surface irrigation systems will see their death in the very near future (Neelakantan, 2003).

Revered Shri Panduranga Shastri Athavale of the 'Swadhyay Parivar' has introduced a movement in Gujarat called 'Nirmal Neer' (clean water) with an aim to provide drinking water and support irrigation through effective rainwater harvesting. Under his inspiration, schemes such as recharging of wells and tube wells, diverting rainwater into the existing ponds as well as construction and maintenance of check dams and ponds have been taken up by the villagers. During 1995, in Saurashtra region alone, people have adopted the recharging of wells scheme in 98,000 wells (Parthasarathi and Patel, 1997). The massive adoption of the scheme explicitly indicates the awareness of conservation and better utilization of rainwater.

Another interesting and innovative initiative by Rajendra singh of TBS has revolutionized the mass movement of the people of Alwar district in the semi-arid Rajasthan state and built bridges of cooperation and solidarity among them. A group of young individuals from TBS took it upon their shoulders, with people's participation and contribution, to rejuvenate defunct *johads* and construct new ones in the Aravari catchment at the foothills of the Shivalik hill ranges of Alwar district. *Johads* are ancient water-harvesting structures, constructed by the people, to store rainwater for multiple uses and to recharge groundwater.

Many *johads* have come up on the tributary streams of the Aravari catchment in the last decade, raising water level in the wells and facilitating irrigation on the cultivated lands. The dead, dry watercourses of the Aravari, which had flowing water only during rainy days in the monsoon months, came alive for the full year. Today, there are more than 200 *johads* in the catchment of Aravari. The successful water harvesting and recharging of groundwater in the upstream of the river followed by scores of *johads* along the main river had transformed the once ephemeral stream into a perennial river. These and other similar movements that are instrumental in achieving productive benefits locally have given rise to many such initiatives in other parts of India.

Artificial Recharging Methods

Definition of artificial groundwater recharge

Artificial recharge is the planned, human activity of augmenting the amount of groundwater available through works designed to increase the natural replenishment or percolation of surface waters into the groundwater aquifers, resulting in a corresponding increase in the amount of groundwater available for abstraction (http://www.unep.or.jp/ietc/publications/techpublications/techpub-8e/artificial.asp). Although artificial recharging is primarily used to preserve or enhance groundwater resources, it has also been used for many other beneficial purposes such as conservation of surface runoff and disposal of flood waters, control of salt water intrusion, storage of water to reduce pumping and piping costs, temporary regulation of groundwater abstraction, and water quality improvement through filtration of suspended solids through soils and other materials or via dilution with naturally occurring groundwater (Asano, 1985). Other areas in which artificial recharge has been used are in wastewater disposal, waste treatment, secondary oil recovery, prevention of land subsidence, storage of fresh water with saline aquifers, crop development and stream flow augmentation (Oaksford, 1985).

The various techniques used for the artificial recharge mentioned earlier have been used successfully throughout India with the notable exceptions of a few areas including Saurashtra and the Karnataka coastal zone. In those areas, the extreme porosity of the aquifer and its connection to the sea means that less water is available for harvest than is injected. In general, artificial recharge works because it is effective in minimizing water loss due to evaporation compared with similar surface storage systems. Many environmental problems arising out of surface storage are also avoided using the method. For example, there is generally no loss of agricultural or other lands by inundation as would occur behind a surface storage structure. In cases where channels are used for groundwater recharge, 'multiple use' benefits have also been achieved.

Classification of recharging methods

To artificially recharge groundwater, different methods have been developed and applied in various parts of the world. Details of these methods, as well as related topics, can be found in the literature (e.g. Todd, 1980; Huisman and Olsthoorn, 1983; Asano, 1985; CGWB, 1994). In summary, artificial recharging may be carried out by direct or indirect methods, or by a combination of methods in an integrated water resources management context.

Direct recharge

Direct surface techniques are among the simplest and most widely used methods for groundwater recharge. Using these techniques, water is moved from the land surface to the aquifer by means of simple infiltration. The infiltrated water percolates through the vadose (unsaturated) zone to reach the groundwater table. Through this process, the recharged water is filtrated and oxidized. Direct recharge methods can be grouped into three categories: (i) when the aquifer is shallow, water may be spread over fields or conveyed to basins and ditches from which it percolates; (ii) when an aquifer is situated at greater depths, recharge can be facilitated by flooding pits and dug shafts; and (iii) in cases of high overburden thickness or confining aquifer conditions, recharge can be effected by injecting surface water directly into the aquifer using boreholes or tube wells.

Water spreading is practised on an increasing scale all over the world and more so in India (Muralidharan and Athavale, 1998). Recharge through pits and shafts has limited applications as recharge capacity is low. However, abandoned stone quarries or open (dug) wells located where the water table has dropped below the excavated depths can be used as ready-made recharge pits and shafts. Recharge through wells can be applied to all hydrogeological situations; however, it might require higher capital and technological requirements. Only surface spreading methods and recharge through dug wells are focused on in this chapter as they are widely used in India.

In some cases where aquifers are under stress, irrigation tanks originally built for surface supplies are being converted into percolation tanks by closing the outlet sluices and allowing the stored tank water to recharge the aquifers. In some groundwater-only areas, surface storage structures (percolation ponds) are being constructed purely for groundwater recharge. In both cases, the percolation tanks (or ponds) are water-harvesting structures constructed across or near streams to impound rainwater and to retain it for a longer time to increase the opportunity time for infiltration. The water storage is expected to induce percolation and replenish the aquifer, which is then exploited through wells located down the gradient. Check dams, generally constructed for soil conservation, can be considered mini-or micro-percolation tanks from which water is not directly drawn for irrigation but is allowed to percolate into subsurface strata, thus augmenting the groundwater.

Most of the evaluation studies on percolation tanks at present are of qualitative nature with limited objective. These are based on the hydrogeological response of the aquifer system or the increase in crop yield. The evaluation studies in southern peninsular India indicate that the recharge efficiency varies between 30% and 60% depending upon the prevailing hydrogeological situation (Muralidharan and Athavale, 1998). The role of the percolation pond in recharging the groundwater has no doubt been realized and appreciated by the farming community in recent years, explaining the growth in application of the technique. However, an improved understanding of the performance of such systems would lead to better siting and effectiveness. Studies on water balances and the interaction between surface and subsurface reservoirs, a critical issue highlighted later, would also help greatly in understanding the value of the practice.

Indirect recharge

Indirect methods of artificial recharge include the installation of groundwater pumping facilities or infiltration galleries near hydraulically connected surface water bodies (e.g. streams or lakes) to lower groundwater levels and induce infiltration from surface water bodies. The effectiveness of induced recharge methods depends upon the number and proximity of surface water bodies, hydraulic conductivity (or transmissivity) of the aquifer, area and permeability of the streambed or lake bottom, and hydraulic gradient created by pumping. Indirect methods generally provide less control over the quantity and quality of the water than do the direct methods. When indirect methods of recharge and retrieval are practised, the water recovered consists of a small fraction of groundwater while a larger fraction of abstracted water comes from river or lake.

There are a number of other indirect recharge methods. For example, in flood irrigation, excess water percolates to the groundwater table. Similarly, seepage from lake beds, irrigation tanks, streams and canals recharges groundwater as does the use of terracing and contour bunds. While recharge from these processes can in some senses be considered accidental, each method's recharge potential can be purposefully enhanced and a combination of techniques, both direct and indirect, can be used to meet specific terrain and topography conditions and recharge needs.

Recharge through integrated water resource development

Groundwater recharge is often best accomplished as a by-product of an integrated water resources development scheme, for example, by increasing groundwater recharge by way of reservoir and canal seepage, injection and infiltration of return flow from irrigation, enhanced infiltration of rainfall as a result of levelling fields for irrigation purposes, and basin development schemes involving the construction of check dams and minor irrigation dams. The Central Groundwater Board (CGWB, 1995) states that nearly 30–40% of applied irrigation water goes as seepage from irrigation fields, a portion of which recharges groundwater. Rates for paddy are much higher than average, ranging from 55% to 88% of the applied irrigation water (Karanth and Prasad, 1979).

An experiment by the Uttar Pradesh government to develop a new and practical way to conserve and rejuvenate falling groundwater reserves through use of flood water highlights the potential for integrated artificial recharge methods. The Madhya Ganga Canal Project (MGCP) located in the lower Ganga canal commands was initiated in 1988. In 2000, the International Water Management Institute (IWMI) carried out a study (Chawla, 2000) on the Lakhaoti branch canal of the MGCP to assess the impact of diversion of surplus Ganga water, during the *kharif* season, on groundwater levels and cropping patterns. The Lakhaoti branch is spread over more than 200,000 ha and covers the districts of

Ghaziabad, Bulandsher and Aligarh in western Uttar Pradesh. It is bounded by the drainage canals of the Kali and Nim rivers.

According to the study, the canal project has helped to raise the groundwater table from 6.6 m to 12.0 m, and brought down the cost of pumping for irrigation from Rs 4500/ha to Rs 2700/ha. Previously, farmers pumped water to irrigate their crops even during the monsoons. This monsoon period pumping lowered the groundwater levels causing severe water shortages during the dry season.

Following the introduction of the MGCP, seepage from the canals and flooded paddy fields helped recharge underlying aquifers. The irrigated area in the project region increased from 1251 ha in 1988/89 to 35,798 ha in 1999/2000, and the area under paddy irrigation was increased to 14,419 ha from 83 ha. The total annual cost of pumping for paddy cultivation due to canal seepage has declined by about Rs 100/ha, resulting in a saving of Rs 180 million for the project as a whole.

Recharge for domestic supplies

The previous section illustrated how irrigation and irrigation-related storage structures can effectively be used to indirectly recharge groundwater aquifers. This section illustrates the role of groundwater recharging for meeting domestic supplies. Artificial recharging of groundwater for domestic supplies assumes significance both in the urban and rural areas of India. Projected water supply requirements for domestic and drinking water needs in 2005 were about 41,000 million cubic metres (Roy, 1993) of which 24,000 million cubic metres was for urban areas and the remaining 17,000 million cubic metres for rural areas. Currently most of the rural and part of the urban drinking water requirements are met from groundwater. In many parts of India, rural drinking water supply programmes often witness shortage of supply from bore wells because of increase in groundwater use for irrigation from boreholes in and around the drinking water bores. The example from different villages of Thumbadi watershed in Karnataka state indicates how lack of effective zoning and regulation of irrigation wells within a 250 m radius of drinking water wells allows irrigation water supply wells to come into existence, hindering the performance of public water supply wells.

The natural recharge studies carried out over different hard-rock terrain indicated that only 5–10% of the seasonal rainfall recharges the groundwater (Athavale *et al.*, 1992). The meagre annual replenishment of natural recharge to the groundwater alone with multiple uses may not be able to meet the projected demand of 17,000 million cubic metres per year by 2050. It is therefore necessary in future to have an independent groundwater source for rural drinking water supply and to protect it as a sanctuary (Muralidharan and Athavale, 1998).

Enhancement of recharge to the groundwater has therefore become mandatory in areas where groundwater is the sole source of drinking water supply. The NGRI (National Geophysical Research Institute) recommends that the methodology of artificial recharge and retrieval (ARR) developed by them can profitably be used for recharging a well during monsoon and using it for drinking water during summer months. Two or three such wells may be declared as sanctuary wells for each village and the ARR scheme may be implemented.

Alternatively, the concept of captive management practice of storing part of the runoff volume in the catchment area through a mini-percolation tank and developing a source well on the downstream side to provide adequate drinking water can be thought of (Muralidharan, 1997). Since the catchment area generally has a shallow basement and low transmissivity, the source well proposed is a large-diameter dug well. Sustainability of the well supply is achieved by constructing a subsurface barrier further downstream on the side of the source well.

Some of the requirement of urban centres in alluvial belts (river alluvium and coastal alluvium) can be met from the groundwater sources. ARR can be implemented on a macro-scale in which millions of litres of good-quality water is transferred to the aquifer every day during monsoon months through a battery of wells, and the same wells can be pumped in summer for feeding water for urban supply of potable water. The NGRI has tentatively identified five areas (Chennai, Kolkata, Mahesana and Chorwond in Gujarat and Jalgaon in Maharashtra) in the country, which have favourable hydrogeological situations for implementing such macro-ARR schemes.

Urban rainwater harvesting and groundwater recharge is catching up in many cities such as Delhi, Chennai and Ahmedabad that are facing acute water supplies, especially in summer and in deficient rainfall years. Many state governments have taken up rooftop rainwater harvesting in a big way. Although a model Groundwater Regulation Bill was circulated among the states by the Government of India as early as 1987, none of the states has adopted either this bill or its modified version to date. Only, the government of Tamil Nadu has enacted a groundwater regulation act pertaining to Chennai metropolitan area to overcome the grave situation it had faced due to severe drinking water crisis.

The Chennai Metropolitan Area Groundwater (Regulation) Act, 27 of 1987, which came into force with effect from February 1988, envisages (i) registration of existing wells; (ii) regulation of sinking new wells; (iii) issue of licence to extract groundwater for non-domestic purposes by the Revenue officials on payment of prescribed fees after getting technical clearance from Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB).

It is due to the implementation of the groundwater regulation act, and other artificial recharge measures adopted, that the water table near the northern part of the city which had an average depth of 8 m before 1988 has risen to an average depth of 4 m below ground level in 2001–2002. As a result of this increase, Metro Water Board has been able to increase the withdrawal from 55 million to 100 million litres per day of water from these well fields during 2003–2004, a year of drought and water crisis in Chennai.

The potential for rooftop rainwater harvesting, based on estimates of rainfall in different parts of the country and the available area of rooftops, has been estimated by the Water Management Forum (WMF, 2003) to be roughly 1 km^3/year. Although this quantity may look small from the overall requirement of the country, this water is critical for drinking water requirements at times of crisis in drought-prone areas.

Costs of Artificial Recharge

For wider adoption of artificial recharging and use of a particular method, the cost of recharge and recovery of various artificial recharge methods is an important parameter that needs to be determined. Full-scale artificial recharge operations in India are limited and, as a consequence, cost information from such operations is incomplete.

The cost of recharge schemes, in general, depends upon the degree of treatment of the source water, the distance over which the source water must be transported and stability of recharge structures and resistance to siltation and/or clogging. In general, the costs of construction and of operation of the recharge structures, except in the case of injection wells in alluvial areas, are reasonable; the comparative costs of recharged water per 1000 m^3 in such cases works out to \$1–3. On the other hand, the cost of using recharged groundwater for domestic water supply purposes, varying from \$0.05 to \$0.15/person/year, is very reasonable, especially in areas where there is shortage of water (CGWB, 1984). The initial investment and operating costs are many times less than those required for supplying potable water using tankers; combining technologies can also result in cost savings. For example, in Maharashtra, the capital cost of combining connector well and tank into a hybrid scheme was about \$900 (the cost of a borehole) compared to the cost of a comparable percolation tank system needed to achieve a similar degree of recharge (estimated to be about \$120,000). Table 10.1 summarizes the estimated costs of various artificial recharge methods.

Contrasting Local and Basin Perspectives On Artifical Recharge

The existence of more than 250,000 tanks and ponds in hard-rock-covered areas of peninsular India itself shows the importance accorded by agriculturalists and rulers for managing the surface water sources locally. However, most of the tanks are old and their storage capacity has reduced due to siltation, and recharge volume of

Table 10.1. Economics of various artificial recharge methods. (From UNEP International Environment Centre, 2004.)

Artificial recharge structure type	Capital cost/1000 m^3 of recharge structure (\$)	Operational cost/ 1000 m^3/year (\$)
Injection well (alluvial area)	551	21
Injection well (hard-rock area)	2	5
Spreading channel (alluvial area)	8	20
Recharge pit (alluvial area)	515	2
Recharge pond or percolation pond (alluvial area)	1	1
Percolation tank (hard-rock area)	5	1
Check dam	1	1

water through the tanks has been considerably reduced. At the same time, the tank command areas have increasingly been put to multiseason cropping use with higher cropping intensities than they were originally designed to meet. As a result, farmers have turned in increasing numbers to the utilization of groundwater through dug and bore wells. The increase in the extraction of the limited renewable groundwater resources has led to a decline in water tables, especially in areas where density of wells is high and rainfall is moderate to low. This in turn has provided the impetus for the groundwater recharge movement.

As briefly discussed, there have been many studies on artificial groundwater recharge that have shown its technical effectiveness. In Maharashtra, it was shown that when tank bottoms were maintained by removing accumulated sediment and debris prior to the annual monsoon, the average recharge volume was 50% of the capacity of the tank (Muralidharan and Athavale, 1998). In Tamil Nadu and Kerala, studies carried out by CGWB on nine percolation tanks in the semi-arid regions of the Noyyal, Ponani and Vattamalai river basins showed that percolation rates were as high as 163 mm/day at the beginning of the rainy season, but diminished thereafter mainly due to the accumulation of silt at the bottom of the tanks (Raju, 1998). In Punjab, studies of artificial recharge using injection wells were carried out in the Ghagger River basin, where using canal water as the primary surface water source showed that the recharge rate from pressure injection was ten times that of gravity systems and that maintenance was required to preserve efficiency (Muralidharan and Athavale, 1998). In Gujarat, studies of artificial recharge were carried out that showed a recharge rate of 260 m^3/day with an infiltration rate of 17 cm/h (Phadtare *et al.*, 1982).

Local level benefits of groundwater recharge in Gujarat

Why artificial recharge is growing in popularity can be seen from an example from India's arid western region. The year 2000 was an unprecedented drought year in Gujarat. The water crisis that year had created an intense awakening among the people of the Saurashtra and Kutch regions about the importance of water. Social workers and NGOs undertook numerous water-harvesting projects to recharge groundwater for domestic and agricultural uses. These projects were often funded by voluntary contributions from affected people. Because of the apparent success of these efforts, under the Sardar Patel Participatory Water Conservation Programme (SPPWCP), the government of Gujarat invested more than Rs 1180 ($28) million in construction of more than 10,000 check dams across Saurashtra, Kutch, Ahmedabad and Sabarkantha regions in 2000/01, which was co-financed by beneficiary contributions. Overall, 60% of the funds was supplied by the government and 40% by direct stakeholders. The responsibility for managing the quality of construction works fell to beneficiary groups and NGOs.

An independent evaluation of the check dams in Gujarat was carried out in 2002 by the Indian Institute of Management (IIM), Ahmedabad, which covered vital aspects of the project including advantages of people's participation and impacts on agricultural production, drinking water supply and availability of fodder as well as overall socio-economic cost–benefit analysis (Shingi and Asopa, 2002).

From the analysis of survey data covering over 100 check dams, personal visits by the evaluation team to a large number of other check dams and interviews with more than 500 farmers, the team concluded that:

1. Localized rainwater harvesting systems in the form of check dams in Saurashtra were an effective solution to the water crisis through their ability to channel rainfall runoff into the underground aquifer. This offered a decentralized system for decreasing the impact of drought and allowed the people's involvement in critical water management tasks with simple, local skill-based, cost-effective and environment-friendly technologies.

2. The rainwater harvesting efforts initiated with people's participation and support from SPPWCP should be relaunched and reimplemented on a larger scale.

3. The 60:40 scheme (60% by government and 40% by beneficiaries) had six major features capable of attracting donor investment: (i) ecologically sound principles behind the concept; (ii) highly participatory nature of the programme, which allowed beneficiaries to contribute their share of the investment through labour, equipment and/or money; (iii) gendered nature of the outcome in that women were the major beneficiaries of the alleviation of drinking water and livestock feed problems; (iv) the fact that the project did not replace or endanger human or wildlife habitat; (v) focus on equitably using renewable resource like rainwater; and (vi) economic and financially sound nature of the work and its short payback period.

4. The 60:40 scheme has been, and should continue to remain, a people's programme, and it is unlikely to survive otherwise. It is felt that only the people's involvement would ensure the survival of critical components like (i) quality of works; (ii) prevention of undesirable contractor's entry into partnership with government; (iii) sustainable maintenance and supervision; (iv) speed of implementation; (v) ingenuity and innovation in implementation; and (vi) cost-efficient technical guidance.

Basin-level costs of groundwater recharge in Gujarat

Some believe that local efforts to increase artificial recharge account for only a small fraction of the massive amount of rainfall on the vast area of any particular catchment or basin. As a result of this thinking, artificial recharge by scattered local communities will not have a perceptible impact on downstream flows or impact downstream surface or groundwater users. However, from a basin perspective, all water use is likely to have some impact on users elsewhere in the system. These impacts are likely to be greatest when basins are 'closed' (i.e. all available supplies have been fully allocated) and in cases with marked inter- and intra-annual variation in rainfall. These are precisely the places and conditions under which groundwater recharge is likely to have the largest local appeal. The potential problems behind this issue are brought out by the following example, which is also from Gujarat.

The watershed known as Aji1 in the Saurashtra region of Gujarat is considered water-scarce and closed, and has high variation in rainfall ranging from

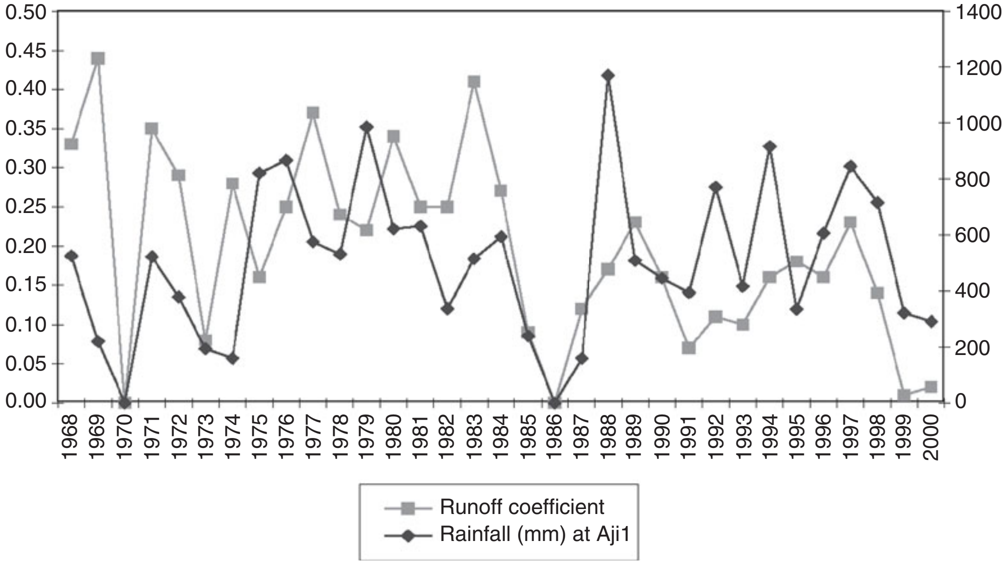

Fig. 10.1. Rainfall and runoff variations in Aji1 watershed from 1968 to 2000.

200 to 1100 mm/year. Aji1 reservoir supplies water to the city of Rajkot, located at the downstream end of the watershed. Starting around 1985, the flow to the reservoir began to decline sharply. It was hypothesized that the decline was caused by the construction of thousands of check dams and percolation ponds within the watershed, the result of a recharge movement initiated by Shri Panduranga Athavale, a religious Guru of Saurashtra, and later supported by the government of Gujarat.

In order to verify whether the decrease in flow into the downstream reservoir was related to the proliferation of upstream check dams and percolation ponds constructed to recharge the groundwater aquifer, rainfall and inflow data to the reservoir was collected for the years 1968–2000 and a simple analysis was made to compute the runoff coefficient as shown in Fig. 10.1. Although rainfall remained approximately the same throughout the period, the runoff coefficient declined markedly, especially after 1985 when the recharge movement reached its full impact. The average reduction in the runoff coefficient after 1985, almost to half of its original value, suggests the extent of the impact the upstream water-harvesting structures had on the downstream reservoir. While the impact of upstream artificial recharge on downstream users in other basins may differ from this example, what is clear is that there will be an impact (Molden and Sakthivadivel, 1999).

Conclusion

The number of groundwater wells in India has increased from less than 100,000 in 1960 to nearly 12 million in 2006. With clear signs of aquifer depletion and continued erratic rainfall, local communities as well as governments are turning to local water-harvesting and recharge structures on a massive scale. The primary objectives of this groundwater recharge movement are to increase groundwater availability for improved security of domestic supplies and to drought-proof and protect rural livelihood. This situation calls for conjunctive water management in a basin context with recharge of groundwater assuming a pivotal role with a caveat that upstream and downstream impact needs to be considered and accounted for.

As described in this chapter, groundwater recharge has a long history in India and there are a variety of direct, indirect and integrated methods at the disposal of farmers, community leaders, NGOs and the government to further expand the movement. The technical issues that these various methods must consider include recovery efficiency, cost-effectiveness, contamination risks due to injection of poor-quality recharge water, and clogging of aquifers. Numerous artificial recharge experiments have been carried out in India and have established the technical feasibility of various approaches and combinations of approaches in unconfined, semi-confined and confined aquifer systems as well as the economic viability.

What is less well understood and appreciated is the potential impacts of numerous local recharge efforts on basin-scale water availability and distribution. The popularity of groundwater recharge is a function of its local success. This, and the critical role of local involvement, highlights the advantages of community approaches to groundwater management described by Schlager (Chapter 7, this volume). However, as shown by the contrast in the two case studies from Gujarat, 'successful' local efforts at recharge can cause problems further downstream. The possible impacts of local action on regional outcomes highlights the key challenge of community-based groundwater governance also described by Schlager – the potential conflict as one moves from local to basin scales.

The reality is that the groundwater recharge movement in India, initiated by local elites and later aided by government and NGOs, has become a people's movement and is likely to stay long into the future. In order to maximize its possible benefits and minimize costs, it has to be nurtured and carried forward with systematic research and development programmes covering its physical, economic, environmental and – what is most lacking now – institutional aspects that can resolve problems across scales.

References

Agrawal, A. and Narain, S. (2001) *Dying Wisdom*. Centre for Science and Environment, New Delhi, India.

Asano, T. (1985) *Artificial Recharge of Groundwater*. Butterworth Publishers, Boston, Masachussetts.

Athavale, R.N., Rangarajan, R. and Muralidharan, D. (1992) Measurement of natural recharge in India. *Journal of Geological Society of India* 39(3), 235–244.

Central Ground Water Board (CGWB) (1994) *Manual on Artificial Recharge of Groundwater*, Technical Series: Monograph No. 3. Ministry of Water Resources, Government of India.

Central Ground Water Board (CGWB) (1995) Report on Groundwater Resources of India. Government of India, New Delhi, India.

Chawla, A.S. (2000) *Ground Water Recharge Studies in Madhya Ganga Canal Project*. Consultancy Report to IWMI, Colombo, Sri Lanka.

DHAN Foundation. (2002) Revisiting Tanks in India. National Seminar on Conservation and Development of Tanks, New Delhi, India.

Huisman, L. and Olsthoorn, T.N. (1983) *Artificial Groundwater Recharge*. Pitman Publishing, Massachusetts.

Karanth, K.R. and Prasad, P.S. (1979) Some studies on hydrologic parameters of groundwater recharge in Andhra Pradesh. *Journal of Geological Society of India* 20, 404–414.

Mission WatSan (1997) Rajiv Gandhi National Drinking Water Mission. Quarterly Bulletin, No. 1.

Molden, D. and Sakthivadivel, R. (1999) Water accounting to assess use and productivity of water. *International Journal of Water Resources Development* Special Double Issue 15(1 & 2), 55–71.

Muralidharan, D. (1997) Captive sustainable drinking water sources well and wasteland development in hard rock areas. Proceedings of National Conference on Emerging Trends in the Development of Sustainable Groundwater Sources, Jawaharlal National Technical University, Hyderabad.

Muralidharan, D. and Athavale, R.N. (1998) Base paper on artificial recharge in India. National Geophysical Research Institute, CSRI, Hyderabad, India.

Neelakantan, S. (2003) *A Gossipmonger's Revisit to Chettipalayam*. Working Paper No. 142. Madras Institute of Development Studies, Chennai, India.

Oaksford, E.T. (1985) Artificial recharge: methods, hydraulics, and monitoring. In: Asano, T. (ed.) *Artificial Recharge of Ground water*. Butterworth Publishers, Boston, Massachusetts, pp. 69–127.

Parthasarathi, G.S. and Patel, A.S. (1997) *Groundwater Recharge Through People's Participation in Jamnagar Region*. Indian Water Works Association, pp. 51–56.

Phadtare, P.N., Tiwari, S.C., Bagade, S.P., Banerjee, A.K., Srivastava, N.K. and Manocha, O.P. (1982) Interim Report on Concept, Methodology and Status of work on Pilot Project for Artificial Recharge, CGWB, Ahmedabad, India.

Raju, K.C.B. (1998) Importance of recharging depleted aquifers: state of the art of artificial recharge in India, *Journal of Geological Society of India* 51, 429–454.

Roy, B.K. (1993) *Population and Reginalisation: The Inevitable Billion Plus*. Editor, Vasant Gowariker. pp. 215–224.

Sakthivadivel, R. and Gomathinayagam, P. (2004) Case studies of locally managed tank systems in Karnataka, Andhra Pradesh, Gujarat, Madhya Pradesh, Gujarat, Orissa, and Maharashtra. Report submitted to IWMI-Tata Policy Programme, Anand, India.

Shah, T. (1998) *The Deepening Divide: Diverse Responses to the Challenge of Ground water Depletion in Gujarat*. Policy School, Anand, India.

Shingi, P.M. and Asopa, V.N. (2002) *Independent Evaluation of Check Dams in Gujarat: Strategies and Impacts*. Executive Summary. Centre for Management in Agriculture, Indian Institute of Management, Ahmedabad, India.

Todd, D.K. (1980) *Groundwater Hydrology*, 2nd edn. Wiley , New York.

WMF (2003) Theme Paper on Inter-Basin Transfer of Water in India–Prospects and Problems, Water Management Forum. The Institution of Engineers (India), New Delhi, India.