Challenges of Groundwater Management in Hard Rock Terrain – A Case Study from Tamil Nadu, India

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Abstract: The yield characteristics of shallow aquifers in hard consolidated rocks, which underlie a major part of India and form important aquifer systems, are severely limited by their considerable heterogeneity and extremely low capabilities for storing and transmitting economic quantities of groundwater. These constraints, coupled with the ever-increasing need for water to satisfy the requirements of a spiraling population, has resulted in the proliferation of groundwater abstraction structures without due regard to spacing norms and environmental considerations. The adverse environmental consequences accompanying this phenomenon, such as de-saturation of shallow aquifer zones and drying up of wells, are often further aggravated by the increasing groundwater extraction from a large number of medium and deep bore wells tapping fracture zones in hydraulic connection with the weathered zone. The properties, that limit the yield of aquifers, also impose severe constraints on the scope for augmentation of resources in depleted aquifers through artificial recharge techniques.

An overview of challenges of groundwater management in the hard rock terrain in the southern Indian State of Tamil Nadu is described in this paper. About 73 percent of the total geographical area of the State is underlain by hard rocks of the Archaean crystalline metamorphic complex. Available surface water resources have already been almost fully developed. Ground water is the major source of water supply for various sectors, accounting for about 50 percent of the net area irrigated. Development of groundwater has traditionally been through large diameter open wells, though a large number of bore wells have become operational in recent years on account of the open wells ceasing to be sustainable due to decline in groundwater levels. The number of open wells in the State has increased from 15.10 lakhs during 1980-81 to 16.6 lakhs during 1999-2000, whereas the number of bore/tube wells has increased from 0.20 lakhs in 1970-71 to 1.63 lakhs during 1999-2000. The decline of groundwater levels due to the over-exploitation of groundwater is considered to have put about 16,000 wells out of use during the nineties. It has also been reported that the average area irrigated by bore/tube wells in the state has declined from 2.10 ha during 1980-81 to about 1.37 ha during 1999-2000 for the same reason. A critical analysis of the assessment of the dynamic groundwater resources of Tamil Nadu based on GEC 1997 methodology indicates that 17 out of 29 districts of the State, underlain almost entirely by hard consolidated rocks, accounted for about 66 percent of the total annual groundwater recharge and about 75 per cent of the gross groundwater draft as in January 1998. This imbalance between the recharge and draft is indicative of the over-exploitation of the limited groundwater resources in the hard rock terrain, which is further substantiated by the fact that more that 70 per cent of the over-exploited and critical blocks are located in these districts.

The large-scale heterogeneity in the properties of aquifer materials even within short distances, lack of availability of source water in sufficient quantities when and where it is required and the lack of proper understanding of hydraulic connection between the weathered zone and fractures, pose serious challenges in attempts to augment the groundwater resources of depleted aquifer zones in the hard rock terrain of the State. The increasing abstraction around recharge sites makes it difficult to quantify the benefits of such schemes realistically. In view of the limitations imposed by nature on the scope for recharge augmentation in hard rock terrain, a two-pronged strategy involving regulation of groundwater abstraction on a regional scale, coupled with cost-effective recharge augmentation at the local level, is likely to be the most effective management strategy for ensuring long-term sustainability of the limited groundwater resources of the State.

INTRODUCTION

More than two-thirds of the Indian sub-continent is underlain by hard crystalline rocks of Archaean age, comprising charnockites, gneisses, granites and associated intrusives for the most parts. In spite of having a very complex, heterogeneous and anisotropic environment, they constitute important aquifer systems catering to the needs of domestic, irrigation and industrial requirements of water in a large number of rural and urban habitations spread all over the country. The occurrence of groundwater in hard crystalline rocks is normally restricted to the weathered residuum at shallow depths and to the inter-connected fracture zones at deeper levels. From a hydrogeological point of view, they have very low to moderate groundwater potentials, depending on topographic set-up, degree of weathering and fracturing and climatic conditions.

The ever-increasing need for reliable sources of water supply to satisfy the needs of a spiraling population, coupled with the rapid pace of urbanization and industrialization, has led to the over-exploitation of groundwater resources in many parts of the country in recent decades. Extraction of groundwater far in excess of the recharge capacity of the aquifers has led to severe environmental consequences such as drying up of shallow wells, long-term decline in water levels and piezometric heads and increasing power requirements for lifting water from progressively deeper levels. Recent developments in drilling and pump-manufacturing technologies have made it possible to extract water from very deep fracture systems, thereby tapping resources hitherto considered 'static'. The limited groundwater potentials and the comparatively long residence times of groundwater in hard rock aquifers, make them highly vulnerable to the perils of over-exploitation, leading ultimately to irreversible socio-economic changes in communities dependent wholly on such sources for their survival.

Contamination of the limited groundwater resources available, either due to natural or anthropogenic factors, also poses a serious challenge to the sustainable management of these resources. Presence of lithogenic fluoride and iron in excess of maximum permissible limits recommended is a major constraint in the efforts of many State governments to provide safe drinking water resources to thousands of habitations, both rural and urban. Nitrate-rich groundwater, caused by the excessive use of fertilizers for agriculture, is now very common in almost the entire country. Contamination of groundwater and soils by untreated or partially treated industrial effluents is another major problem that is becoming more and more severe with every passing year.

THE TAMIL NADU SCENARIO

Background Information

Tamil Nadu, the southern-most State of India (Fig. 1), having a total geographical area of about 130,060 sq. km. is well known for its perennial water-related problems. The State has a population of about 62 million as per the 2001 census, about 56 per cent of which resides in rural areas. Accounting for about 7% of total population of the country, it is endowed with only 3% of water resources of India. The State's water resources are dependent mainly on monsoon rainfall. The annual precipitation ranges from about 850 mm in the inland plains to about 1700 mm in the hilly regions. The State receives rainfall in two distinct seasons, viz., SW monsoon (June to September) and NE monsoon (October to December). The winter season lasts from December to February and the hot summer season from March to May. About 46% of the normal annual rainfall is received during the northeast monsoon whereas about 35% is received during the southwest monsoon. Rainfall during summer and winter seasons contribute about 14% and 5% respectively.

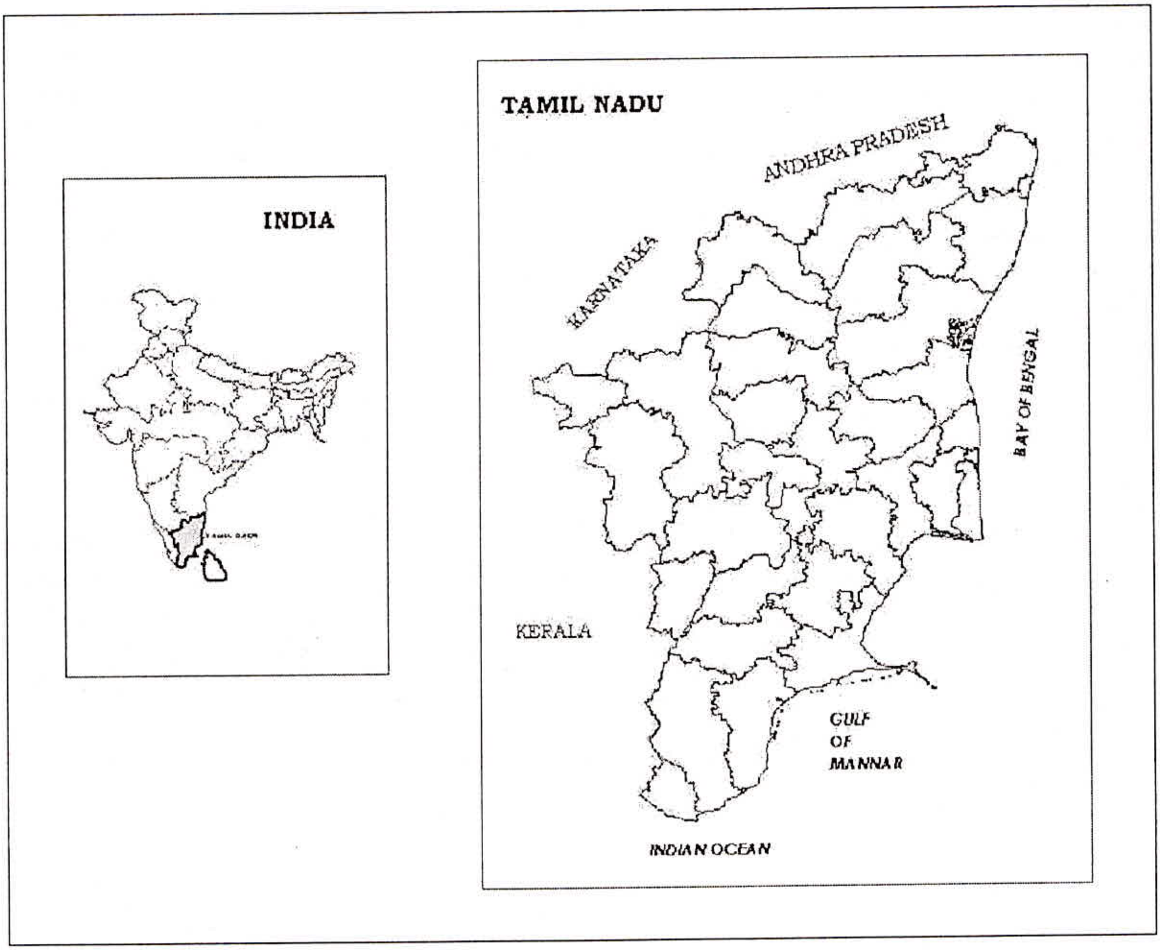

Fig. 1. Location map of Tamil Nadu.

Crystalline rocks belonging to the Archaean Metamorphic Complex comprising charnockite, gneisses, granites and associated intrusives underlie about 73 per cent of the total geographic area of Tamil Nadu. The remaining area, mostly confined to the eastern coastal tract, is underlain by semi-consolidated and unconsolidated sedimentary formations consisting of sandstones, clays, pebbles, gravels, limestone and shale belonging to Mesozoic, Tertiary and Quaternary era.

The hydrogeological framework of Tamil Nadu is controlled to a large extent by the distribution of rainfall and by its geological, structural and morphological configuration. Ground water occurs in all the geological formations. Rainfall, seepage from reservoirs, canals, irrigation tanks and irrigated fields constitute the major sources of recharge into the aquifers, whereas extraction of groundwater for various uses constitutes the major component of groundwater draft.

Water Resources Development

The total water resources in Tamil Nadu including groundwater is estimated to be of the order of 46,540 MCM (1643 TMC), out of which the surface water potential is about 24,160 MCM (853 TMC) including the contribution (7391 MCM or 261 TMC) from the neighbouring States, viz., Kerala, Karnataka and Andhra Pradesh (State Planning Commission, Government of Tamil Nadu, 2005). As on date, the surface water potential available in the State has almost completely been utilized and consequently, groundwater has become the major source of water for domestic, irrigation and industrial sectors in the State. The increasing dependence on groundwater as the major source of irrigation water supply is clearly brought out by the comparison of per cent source-wise area irrigated in Tamil Nadu during 1950–2003 (Fig. 2).

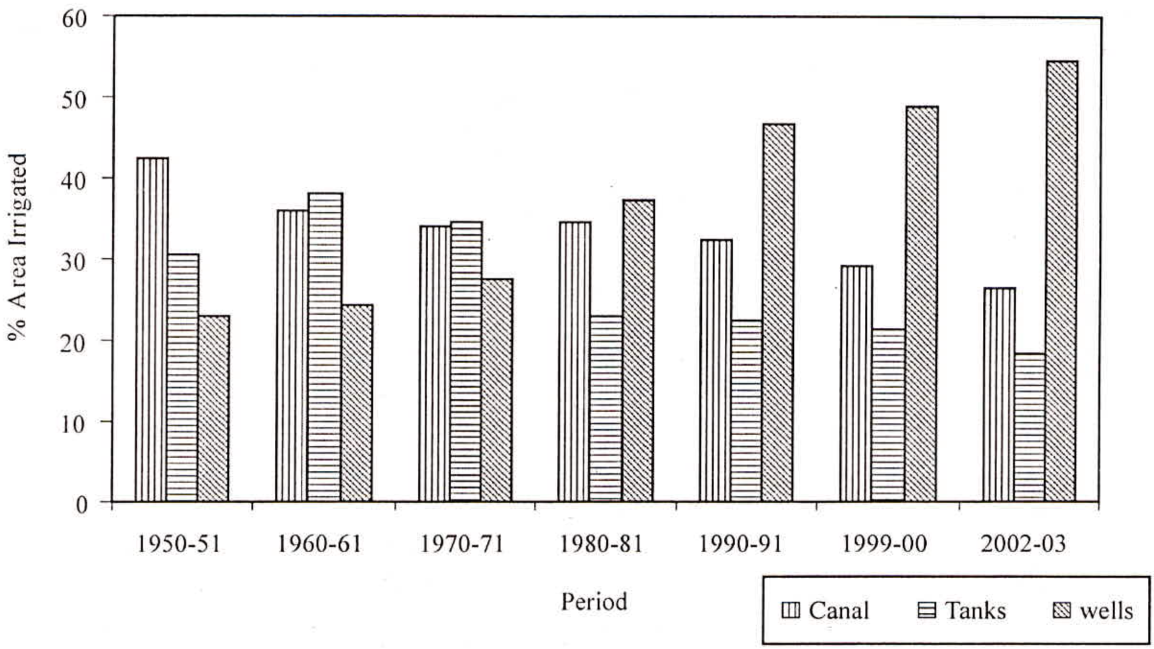

Fig. 2. Source-wise percentage area irrigated in Tamil Nadu (1950–2003).

Source: Season and Crop Reports, Govt. of Tamil Nadu.

The emergence of groundwater as the major source of irrigation has led to significant changes in the groundwater development scenario of the State. Large diameter open wells, which have been traditionally the most common groundwater abstraction structures, gradually lost ground, as they could not cope with the ever-increasing demand for water. The lack of sustainability of dug wells, coupled with the recent advances in drilling and pumps manufacturing technology, led to the large-scale proliferation of medium to deep bore wells in most of the districts of the State. As per data available (Dept. of Applied Research, Govt. of Tamil Nadu, 2002), the number of dug wells in Tamil Nadu had increased from 15.1 lakhs in 1980-81 to 16.6 lakhs in 1999-2000. On the other hand, the number of tube wells had increased from 0.20 lakhs in 1970-71 to 0.90 lakhs in 1990-91 and further to 1.63 lakhs in 1999-2000, indicating that there has been phenomenal growth in the number of bore/tube wells in the State since 1990. The rapid pace of energization of wells, from 42.4 per cent during 1970-71 to 73.3 per cent during 1990-91 and to 91.1 per cent by 1999-2000, probably due to the supply of free electricity for agriculture, has also resulted in the increase in groundwater development substantially.

The rapid increase in the development of the limited groundwater resources has resulted in various environmental impacts in the State such as drying up of shallow wells, long-term decline in groundwater levels and piezometric heads and increase in the consumption of electricity for pumping water from progressively deeper levels. The large-scale extraction of water from the fractured aquifers has also resulted in the de-saturation of weathered phreatic aquifers in hydraulic connection with the fractured aquifers, which in turn, has contributed to the non-sustainability of dug wells. It has been reported that as many as 16,000 irrigation wells could not be put to use for irrigation in the State due to declining water levels. The progressive declines in the yields of wells are also indicated by the reported reduction in the average area irrigated by bore/tube wells in the State from 2.1 ha during 1980-81 to 1.89 ha in 1990-91 and 1.37 ha in 1999-00.

Various aspects of groundwater development in Tamil Nadu, described above, are shown diagrammatically in Fig. 3.

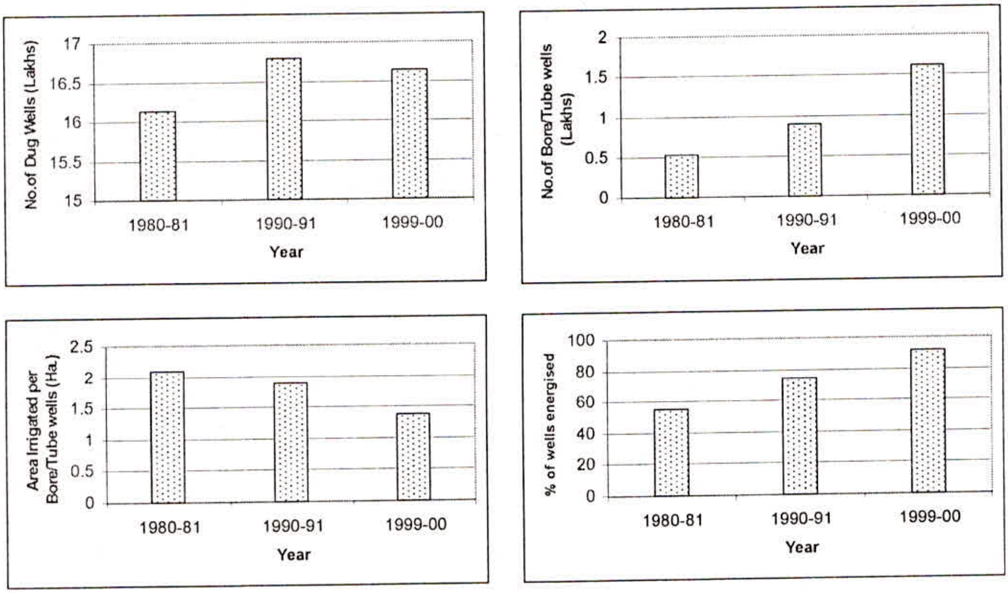

Fig. 3. Various aspects of development of groundwater resources in Tamil Nadu.

The historical water level data of groundwater monitoring wells of CGWB has been used to study the long-term behaviour of groundwater levels in Tamil Nadu (CGWB, 2005). A comparison of water levels recorded during 2004 with the average water levels for the previous decade (1994-2003) indicates the following.

i) During pre-monsoon period (May 2004), about 62 per cent wells monitored in Tamil Nadu have recorded a fall in comparison to the average pre-monsoon water levels of the previous decade.
ii) As far as the districts underlain entirely by hard crystalline rocks are concerned, decline in water levels was observed in about 65 per cent wells monitored. In the districts underlain mostly by sedimentary rocks, about 57 per cent have recorded a long-term decline.
iii) During post-monsoon period (January 2005), about 55 per cent wells in hard rock terrain and 51 per cent wells in sedimentary rocks have recorded declines in water levels when compared to mean water levels for the previous decade.

As per the report on dynamic groundwater resources of Tamil Nadu as in January 2004, published jointly by the State Ground and Surface Water Resources Data Centre, Water Resources Organization (PWD), Government of Tamil Nadu and Central Ground Water Board, Ministry of Water Resources, Government of India, the net annual groundwater availability in Tamil Nadu is of the order of 20,763 Million Cubic Metre (MCM), whereas the gross groundwater draft for all uses is of the order of 17,227 MCM. After allocation of resources for meeting the demands of domestic and industrial sectors for the next 25 years, the net groundwater availability for future irrigation development in the State has been estimated as 3303 MCM. The stage of groundwater development, computed as the ratio of gross groundwater draft and net groundwater availability, works out as 64 per cent.

Analysis of district-wise data used for the assessment of groundwater resources indicate that 17 districts in the State, underlain almost entirely by hard crystalline rocks, account for nearly 66 per cent of the net groundwater availability and about 75 per cent of the gross groundwater draft. It is also seen that these districts have more than 70 per cent of the over-exploited and critical blocks in the State as in 2003 (Fig. 4). These statistics are indicative of the imbalance that exists between the recharge and draft, which has led to the over-exploitation of groundwater resources in the hard rock terrain when compared to the area underlain by sedimentary formations.

The forgoing analyses clearly indicate that the over-exploitation of groundwater has resulted in severe stress on the limited groundwater resources of Tamil Nadu as a whole and in the hard rock terrain of the State in particular.

CHALLENGES OF GROUNDWATER DEVELOPMENT AND MANAGEMENT IN HARD ROCKS

The hard, consolidated rocks underlying a major part of Tamil Nadu are devoid of primary porosity but are rendered porous and permeable due to the development of secondary openings as a result of weathering and fracturing. The occurrence and movement of groundwater and the productivity of hard rock aquifers are governed by the amount of precipitation, geomorphologic set-up and the degree of weathering and fracturing. Joints, fractures and shears act as conduits facilitating storage and movement of groundwater within these rocks. Ground water normally occurs under phreatic conditions in the weathered mantle and under semi-confined conditions in the fracture zones. These aquifers are highly

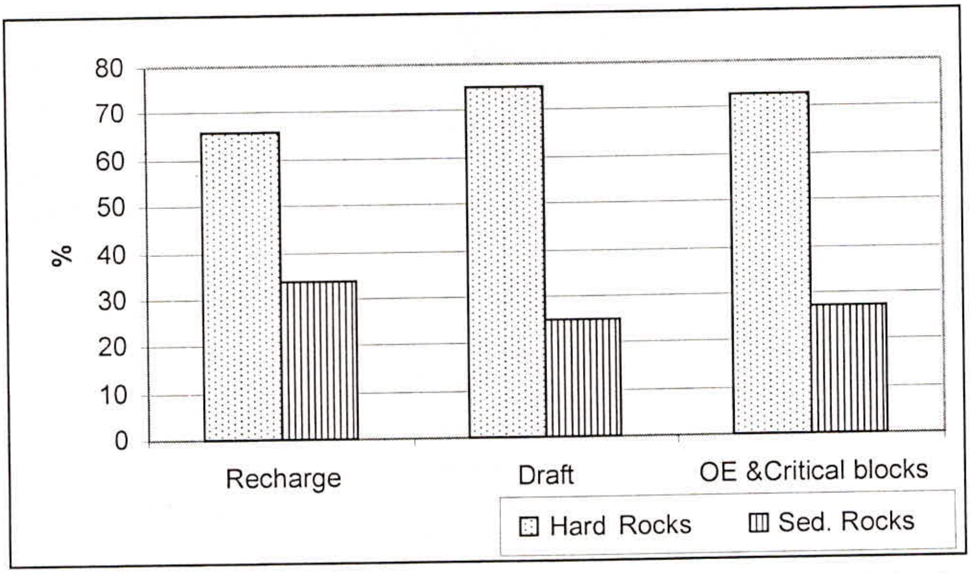

Fig. 4. Comparison of groundwater recharge, draft and number of over-exploited and critical blocks in Tamil Nadu, as in 2003.

heterogeneous and anisotropic in nature. The weathered mantle essentially consists of disintegrated material followed by jointed and fractured crystalline rocks, constituting shallow water table aquifers. These aquifers occur within 25 m below the ground level in the major part of the State except in the west, where they are deeper. Topographic lows, buried pediments, zones of intersections of weaker planes and hydraulic troughs in morphological depressions are preferred locales for groundwater development in hard rock terrain.

The major challenge of groundwater development in hard rock terrain is the uncertainty of obtaining adequate and sustainable yields from the weathered and fractured aquifers. In spite of the use of advanced technologies of remote sensing, hydrogeological and geophysical investigations, it is still difficult to predict the yield of bore wells in the majority of cases unless and until the well is drilled. The aquifer geometry, fracture pattern, fracture conductivity and yield characteristics show wide variations even within short distances. This uncertainty often results in the proliferation of wells in 'proven' areas and leads to unhealthy competition among the stake-holders without due regard to the recharging capacity of aquifers and spacing between the wells, leading to pockets of over-exploitation of groundwater resources. The prevalence of small land holdings is another factor responsible for the large number of groundwater abstraction structures in the State.

The rapid increase in the number of bore wells in the hard rock terrain has been one of the major contributing factors responsible for the reduction in the sustainability of dug wells. The indiscriminate pumping from deeper aquifers has resulted in considerable de-saturation of the water-table aquifers in hydraulic connection with the fracture systems, thereby making the dug wells non-sustainable. This has also resulted in serious socio-economic consequences as the small and marginal farmers, without the necessary resources to construct deep bore wells, are entirely dependant on dug wells as the source of irrigation and find themselves unable to eke out a living from the small pieces of their land due to lack of water in their wells.

The pollution of groundwater resources due to natural and anthropogenic contaminants also poses severe constraints in the development of groundwater resources in the State. In the hard rock terrain, presence of geogenic fluoride and iron in excess of the maximum permissible limits recommended for drinking, severely affect the development prospects of groundwater in many districts such as Dharmapuri, Salem, Coimbatore and Vellore. Presence of high nitrate in groundwater, attributed to the excessive use of nitrogenous fertilizers and the pollution by effluents from industries such as tanning, bleaching etc. have also become issues of concern in the last few decades in the State. The rapid pace of urbanization has also resulted in the large-scale contamination of groundwater resources in many peri-urban areas in the hard rock terrain of the State, such as those of Coimbatore, Madurai and Salem.

The characteristics of aquifers that restrict the yields of groundwater abstraction structures impose severe restrictions on the prospects of groundwater augmentation through artificial recharge in the hard rock terrain. Owing to the large-scale anisotropy and heterogeneity, the efficacy of recharge structures and their impact on the groundwater regime in such terrain is highly localized and site-specific. Though schemes implemented in the State for augmentation of groundwater in phreatic aquifers through artificial recharge structures, such as percolation ponds and check dams, have been found successful when implemented for the watershed as a whole, direct augmentation of groundwater resources in the deeper fractured aquifers have yet to be proved effective, mainly due to the lack of understanding of the aquifer geometry and fractures connectivity. The un-regulated extraction of groundwater all around recharge structures makes it almost impossible to have a realistic assessment of the impact of many such schemes implemented by various Central and State agencies. The environmental impact of recharge projects, in such cases, has to be based on the indirect impacts such as increase in the sustainability of wells or increase in the crop yields (Central Ground Water Board, 2003).

Owing to the increasing awareness on the importance of groundwater conservation and the initiatives taken by Central and State governments for promoting recharge augmentation, a large number of artificial recharge structures have been constructed in Tamil Nadu in the last decade or so. However, realistic estimates of the impact of these structures on the groundwater regime are not readily available, except in a few cases. The construction of artificial recharge structures, without due regard to the availability of surplus runoff and the characteristics of the sub-surface formations, have resulted in many such structures being ineffective in recharging the de-saturated aquifer zones.

MANAGEMENT OPTIONS

The analysis of data on various aspects of groundwater development in Tamil Nadu indicates that the inherent characteristics of aquifers, unbridled growth of groundwater abstraction structures and pollution of the limited resources due to natural and man-made contaminants are the major factors responsible for the prevailing stress on groundwater resources in the hard rock terrain. The availability of free supply of electricity for groundwater extraction for irrigation and cultivation of water-intensive crops without due regard to the yield characteristics of aquifers, have also resulted in accelerating the groundwater over-exploitation in parts of the State. Lack of availability of surplus run-off and the inherent characteristics of the aquifer systems limits the scope for augmentation of groundwater resources on a regional scale.

In such a scenario, a two-pronged approach, consisting of regulations on groundwater extraction on a regional scale, coupled with intensive recharge augmentation at the local level, could be the only viable alternatives to ensure long-term sustainability of groundwater resources in the hard rock terrain of Tamil Nadu. Identification of surface water and groundwater resources that could be developed for use on a sustainable basis should be combined with initiation of programmes for the protection, conservation, and rational use of the resources. Effective groundwater pollution prevention strategies including strategies for prevention of pollution at source, environmental impact assessments and enforceable water quality standards commensurate with the socio-economic status of the area concerned should be initiated. Stakeholder participation is another necessary prerequisite for the success of any water management initiatives by the State or Central government. Long-term strategies including changes in cropping pattern to suit the availability and quality of groundwater may also have to be contemplated to ensure environmentally sound water management. More studies on development and geometry of fracture systems in hard crystalline rocks may be necessary to gain a better understanding of the hydrodynamics of hard rock aquifers, which will go a long way in the efforts to manage their limited resources through a judicious combination of controlled exploitation, effective regulation and augmentation of resources.

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