Hydrology of the Mediterranean and Semiarid Regions (Proceedings of an international symposium held at Montpellier, April 2003). IAHS Publ. no. 278, 2003.

The impact of anthropogenic factors on groundwater regime in crystalline hard rock aquifers, in Andhra Pradesh, India

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Abstract Semiarid tropics cover the largest area of the Indian subcontinent underlain by compact and hard rocks, characterized by seasonal rainfall of a highly fluctuating nature, both in space and time. As a consequence of the industrial and green revolutions of India during the past three decades, large-scale development of groundwater using improved technologies of drilling and abstraction has been commissioned. In addition, the increased demands from the industrial and farming sectors have emerged as major constraints to economic growth and quality of life improvement. The present scenario in many parts of South India shows a significant decline in groundwater levels in addition to quality deterioration. The effects of anthropogenic activities on the groundwater system in some hard rock regions of South India underlain by the crystalline rocks are evaluated in studies that include both urban and rural areas, possible management practices and remedial measures. The findings indicate that proper and judicious management, initially, could improve the situation, and then a suitable resource augmentation or artificial recharge scheme should be adopted.

Key words anthropogenic; crystalline rocks; groundwater; semiarid-tropics; urban hydrology

INTRODUCTION

In South India, hard rocks, mainly crystalline, are composed of two important layers important for the movement and storage of groundwater. The first 15–20 m are composed of weathered layers; below are fractured and hard massive impervious rocks. The "hard rocks" form a significant group and occupy about 65% of the total land area of India. Stratigraphically they range from Archaean to Recent (laterites). These Precambrian shield areas pose special problems for groundwater exploration and exploitation because their permeability and storage capacity depend exclusively on fractures. Since the fracture disposition, length and apertures are distributed randomly, it is difficult to regionalize the local hydraulic properties of these fractures into coherent patterns of groundwater occurrence (UNESCO, 1984).

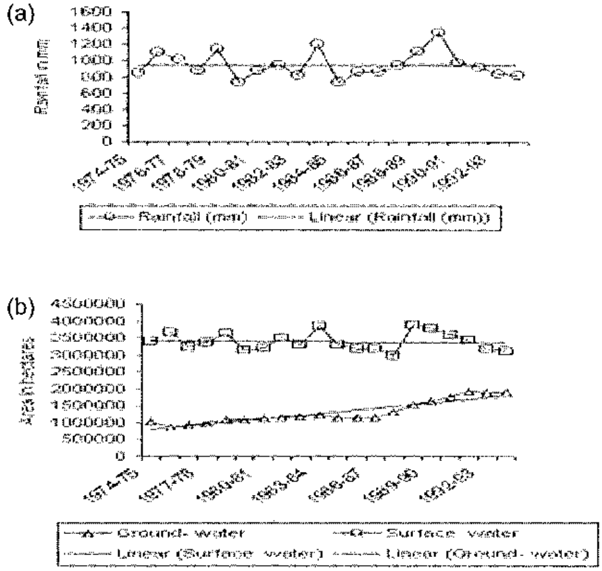

Fig. 1 Development of irrigated land through surface water and groundwater vis-à-vis rainfall in Andhra Pradesh.

In many parts of Andhra Pradesh, the annual rainfall is less than 1000 mm $year^{-1}$, and the use of surface water irrigation tends to follow the rainfall pattern. However, the use of groundwater for irrigation has increased many fold, because the farming sector raises three crops during a year (Fig. 1). This practice has resulted in the over exploitation of the limited resource, often exceeding the mean annual recharge contribution (roughly 10%) by infiltration.

There has been an accelerated development in the use of groundwater during recent times, since demands for both industry and irrigation have increased many folds. Also due to the advent of modern techniques, the simplicity in the construction of bore wells and the viability of exploiting deeper fractured aquifers, the practice of construction of open-dug wells has almost been replaced by drilling of bore wells. The advantage of quick drilling techniques in hard rocks has encouraged many users to drill to deeper depths in the hope of getting higher yields. The net result of indiscriminate drilling has resulted in the decline of water levels to far below the weathered layer, decrease in well yields and groundwater quality deterioration (Babu Rao *et al.*, 2001).

GROUNDWATER OCCURRENCE IN HARD ROCKS

Groundwater occurs in the upper weathered mantle of the underlying hard rock formations and in the fractures and joint planes. The faults and shear zones also contain copious supplies of groundwater. Sometimes the groundwater flow velocities in fractured rocks far exceed those obtained in the alluvial formations. The average yield of wells in these rocks ranges from 10 to 100 m^3 day^{-1}. Transmissivities also range from almost negligible to an average value of 100 m^2 day^{-1} but may exceed

400 m^2 day^{-1} in tectonically disturbed areas and along lineaments (data obtained from about 100 pumping tests conducted by the first author in parts of Andhra Pradesh).

A change in the well construction is the most important feature that has changed the groundwater scenario. The depths of the bores were in the range from 25 to 30 m during 1970–1980. Due to further increasing demands commensurate with a large influx of rural population to the urban areas, during 1990–2000 bore wells have been drilled to depths of more than 60 to 70 m. The net result of drilling has caused a large part of the weathered zone to get dried up.

URBAN HYDROLOGY (HYDERABAD)

An unplanned expansion of Hyderabad, the capital city of Andhra Pradesh, has had alarming impacts on the hydrogeological setting. About 75% of the area is covered by the urban conglomeration and the rest is occupied by hilly terrain. The population is about 5.7 million (District yearbook, 1999). Urban domestic and industrial consumers are using larger amounts of water and, consequently depleting the available sources and simultaneously degrading these resources with the wastes. The groundwater has been tapped very extensively through a large number of bore wells to meet the increasing demand for domestic and industrial use. Historical water level data for the past two decades indicates that there is a decline of 6 to 8 m in the discharge zones, while it is more than 12 to 15 m in the catchment areas (peri-urban areas).

The scenario

The annual long-term average rainfall in the area, including urban and sub-urban, varies from 780 to 800 mm. The annual groundwater recharge, based on average fluctuations of water levels in 30 observation wells in Hyderabad urban area, have been estimated by the Andhra Pradesh State Groundwater Department (unpublished reports of APSGWD, 1995). It was found that the recharge to the groundwater was reduced from 80×10^6 m^3 in 1987 to about 20×10^6 m^3 in 1994, due to the expanding urban development and concomitant reduction of land surface for infiltration (Fig. 2). A recent survey (June 2000) indicates that the water striking horizons are at a minimum depth of 30 m below land surface. Though these wells have tapped deep fracture systems, it is apparent that the connectivity among the deeper fractures is not very well established and that the yields are not substantial, often just sufficient for domestic consumption of about 70–120 m^3 h^{-1}, for a pumping schedule of 2 to 3 h daily on average. Marsily (1992), commenting upon these deep confined aquifers expresses concern regarding their vulnerability to pollution, in the absence of controlled pumping. He advocates that "extreme precautions and limitations of draw down must be imposed to prevent long-term pollution by downward leakage of contaminated surface water".

The comparison of 1970 chemical data pertaining to shallow wells and boreholes (information prior to urbanization) with that of 1997 suggested that the most affected (contaminated) areas coincide with that of urbanization and adjacent to industrial areas (Fig. 3). The groundwater quality of dug wells (shallow weathered aquifer) monitored

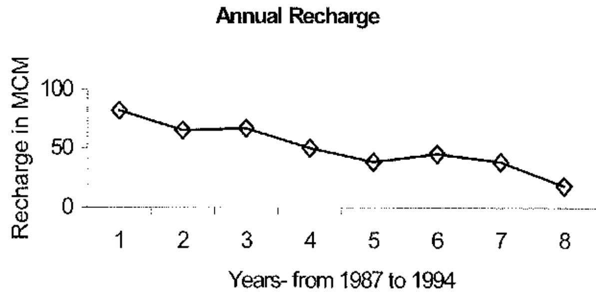

Fig. 2 Reduction in recharge due to urbanization of Hyderabad.

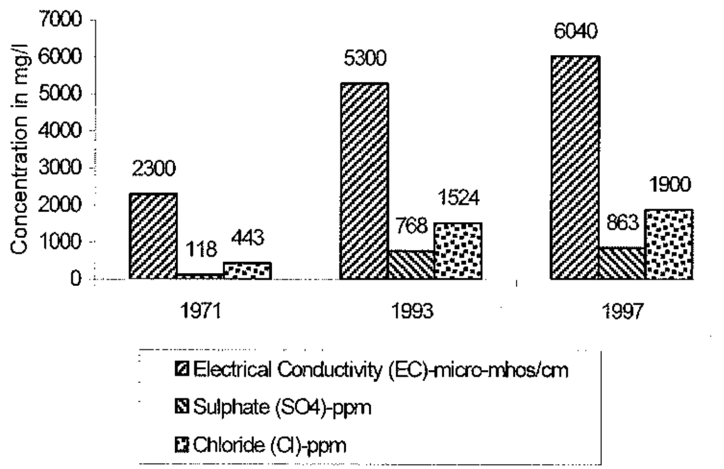

Fig. 3 Significant changes in groundwater composition over two decades.

during 1979–1980 (Papireddy & Venkaiah, 1981) in southern parts of Hyderabad Urban is classified as belonging to calcium–magnesium–bicarbonate type. The results of groundwater quality studies in the vicinity of Milwaukee, Wisconsin, USA, indicate that chloride and sulphate are the principal products of urbanization, which alter groundwater chemistry (Craig & Anderson, 1979). The Central Groundwater Board in Hyderabad has conducted water analysis during 1995 and 1999 (unpublished reports of CGWB, 1995, 1999). In general, the groundwater was classified as belonging to chloride–sulphate facies. The abnormal increase in the contents of Cl, SO_4 and NO_3 in the groundwater (Fig. 3) is a definite indication of the inadequate provision of sewage disposal systems and disposal of industrial effluents into the drainage network. Lakes serve as traps for pollutants carried by streams and groundwater draining the basin. The production of biomass and its decay results in decreased oxygen levels, and release of odorous compounds (H_2S) and siltation. As a result of unabated disposal of wastewaters and industrial effluents, the Hussain Sagar lake in the city has reached to advanced eutrophication levels.

Excessive development of groundwater sources on one hand and construction of human dwellings in the foreshore areas of several tanks/lakes in the Hyderabad city on the other hand, had a dual effect on the groundwater set-up. The water levels have declined with related decrease in recharge as the surface areas have been reduced for natural infiltration and replenishment of the aquifers. There is a mushrooming growth of slums and residential colonies all over. Some of the issues relating to groundwater in urban environment include: (a) disruption in the natural hydrological cycle, causing a reduction in the natural recharge and increasing runoff due to changes in land use pattern; (b) declining water levels due to groundwater mining; and (c) increased pollutant loads to water courses and surface water bodies from runoff.

Possible remediation

Some irregularities in the city planning could be rectified and the situation improved as a first step to recover the situation. They could be following: 1. Stopping settlement in the catchment and recharge area of the basin. 2. Design and construction of satellite cities with sufficient open intermediate areas. 3. Design and maintenance of proper drainage system.

The above situation would improve the scenario to a great extent and then augmentation structures for groundwater resource could be designed for specific sites. Some of the methods for augmenting the groundwater could be: 1. Roof top collection of rainwater. 2. Design of tar roads with sides open to infiltration/runoff collection pits. 3. Encouraging individual houses with gardens and/or maintaining sufficient distance between the multi-storied buildings.

RURAL HYDROLOGY (MAHESWARAM)

In a small watershed of about 60 km^2 in the Maheswaram mandal of Ranga Reddy district, Andhra Pradesh, underlain by granitic rocks, water level monitoring is being carried out regularly for about 600 wells to study the water level fluctuations with respect to rainfall, spatio-temporal variability and local pumping. There are three types of fracture patterns in the area: (a) mineralized fractures, (b) fractures traversed by dykes, and (c) late stage fractures represented by joints.

The scenario

Groundwater flow systems are of the local type, a local system having its recharge area at a topographic high and its discharge area at a topographic low which are adjacent to each other. Intermediate and regional groundwater flow systems do exist since hydraulic connectivity exists with depth. In addition, to the permeable saprolite layer, aquifers occur where bedrock and the quartz pegmatite intrusive veins are jointed and fractured.

Although the rainwater input, by and large is around 500 mm and the recharge around 9%, (Rangarajan & Prasada Rao, 2001), there has been depletion of the water levels of about 10 m during the two decades due to over abstraction causing the weathered zone to become completely dry. The transmissivity of the fractured aquifers vary considerably from about 30 m^2 day^{-1} to about 230 m^2 day^{-1}, and the low storage coefficient indicates the limited potential of the aquifers and its consequent doubtful sustainability. The impact of agricultural manures on the groundwater is seen increasing the chloride and nitrate contents. Though not an anthropogenic source, the excessive development of groundwater has enhanced the fluoride concentration due to dissolution processes.

Possible remediation

It is necessary to increase awareness that uncontrolled groundwater pumping results in declining water levels, abnormal costs for uplift, and decrease in safe storage. Thus it should be pumped only when required, storing in the surface tanks will enhance soil salinity and subsequently water salinity.

- The style of irrigation should be changed; it is better to adapt to other crops that require less water. Only two crops of paddy rice should be grown in a year. More rain-fed crops should be encouraged.
- Depending on the availability of surface and/or groundwater, agricultural practice should be adapted.
- Groundwater should be protected from surface pollution including the domestic waste, septic tank design etc.

Nevertheless, groundwater resource augmentation by artificial recharge is essential as the period of rainfall is very short. Thus following artificial recharge schemes should be designed, particularly for the crystalline hard rock aquifers, incorporating: (a) revival of defunct dug wells, (b) contour bunding, and (c) check dams across small catchments.

CONCLUSIONS

As a result of over-exploitation, a general decrease in piezometric levels has been observed in many places in India particularly in hard rock aquifers (i.e. plutonic and metamorphic rocks with fracture permeability). The natural recharge is lower than the pumping rate and the groundwater reserves are being increasingly depleted. The ecological degradation resulting from soil erosion and enhanced runoff, have affected groundwater recharge. Moreover the decrease in piezometric levels has reduced the base flow of rivers during dry periods when groundwater contributes to a part of the flow.

No reliable estimates of the groundwater potential of these aquifers could be made as the methods employed are mostly empirical and leading to approximate results. Discrete-fracture network (DFN) models are being applied to define the flow paths more explicitly (Barker, 1988). Though in principle these models could be applied to the hard rock aquifers, a detailed site-specific characterization is an integral component of the model. For long-term development and sustainability of the available resources, the catchment areas must be protected from overexploitation and water quality degradation by untreated sewage, industrial waste and agricultural chemicals.

Management practices may include: (a) drip and sprinkler irrigation systems will prove to be cost effective and more useful in low groundwater potential areas, (b) harnessing of rainfall, surface run-off and protection of lake systems.

Acknowledgements The authors are thankful to the Director, NGRI for having given the permission to publish the paper.

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