GROUNDWATER DEVELOPMENT IN HARD ROCKS

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Summary

Groundwater development in fractured hard rock aquifers has always assumed a secondary role compared with that in unconsolidated alluvial strata or in soluble carbonate rocks. This is because of the nonextensive, irregular, nonisotropic, and inhomogeneous nature of the aquifer and the relatively small yields of water available from dug-wells or drilled bores. However, many of the highly populated areas in the world are underlain by hard, fractured rock aquifers. Whatever small supply of groundwater is available from these aquifers is the only source for millions of people to obtain their drinking water supply and to irrigate their small plots of farms. In India and many other countries, institutional finance at concessional rate of interest has been provided to farmers since the early 1970s for well digging/drilling for irrigational use. This resulted in overdevelopment in some sub-basins, thereby stressing the need to promote recharge augmentation. For sustainable development, it is necessary to adopt soil and water conservation techniques in each watershed, taking a sub-basin as the unit for planning. This article discusses various aspects of groundwater development in hard, fractured rock aquifers including occurrence of water, types of wells, exploration, recharge augmentation, and legal control of pumpage.

1. Introduction

Development of a natural resource like groundwater is a concerted activity towards its sustainable use for the benefit of humankind. The concept of sustainable use is quantitatively related to various factors like the volume of the existing resource, annual recharge or replenishment, benefit/cost ratio of the proposed use, and environmental impacts of the proposed use.

Hard rock aquifers for the purpose of this article mean the noncarbonate, fractured rock aquifers in the terrain covered by crystalline basement complex and metamorphic rocks. Extensive, ancient volcanic rocks like basalts of western India (Deccan traps), which are more compact and impervious than recent volcanic effusions, are also included as a special case, in this discussion. Hundreds of nearly horizontal, basaltic lava flows form a thick pile, known as Deccan traps, which cover around 500 000 sq. km in western India. This pile was not tectonically disturbed after consolidation and a hand specimen does not show any primary porosity due to the nonfrothy nature of the lava. Hydrogeologically, this rock resembles the fractured basement complex.

The most significant features of the hard rock aquifers are as follows:

- A topographical basin or a sub-basin generally coincides with groundwater basin. Thus, the flow of groundwater across a prominent surface water divide is very rarely observed. In a basin, the groundwater resources tend to concentrate towards the central valley portion, closer to the main stream and its tributaries.
- The depth of groundwater occurrence, in useful quantities, is usually limited to 100 meters or so.
- The aquifer parameters like storativity (S) and transmissivity (T) often show erratic variations within small distances. The annual fluctuation in the value of T is considerable due to the change in saturated thickness of the aquifer from wet season to dry season. When different formulae are applied to pump-test data from one bore well, a wide range of S and T values is obtained. The applicability of mathematical modeling is limited to only a few simpler cases.
- The saturated portion of the mantle of weathered rock or alluvium or laterite, overlying the hard fractured rock, often makes a significant contribution to the yield obtained from a dug well or bore well.
- Only a modest quantity of groundwater, in the range of from 1 m^3 to 100 m^3 or so per day, is available at one spot. Drawdown in a pumping dug well or bore well is often almost equal to the total saturated thickness of the aquifer.

Groundwater development in hard rock aquifer areas has always played a secondary role compared with that in the areas having high-yielding unconsolidated or semiconsolidated sediments and carbonate rocks. This has been due to the relatively poor groundwater resources in hard rocks, low specific capacity of wells, erratic variations and discontinuities in the aquifer properties, and difficulties in exploration and quantitative assessment of the resource.

It should, however, be remembered that millions of farmers in developing countries have their small farms in fractured basement or basaltic terrain. Whatever small supply is available from these poor aquifers is the only hope for these farmers for upgrading their standard of living by growing irrigated crops or by protecting their rain-fed crops from the vagaries of rainfall. It is also their only source for drinking water for the family and cattle. In many developing countries, hard rock hydrogeologists have, therefore, an important role to play. In the developed countries, the interest in hard rock hydrogeology, apart from drinking water supplies to small communities, has been recently promoted by the prospects of using these low permeability rocks for the storage of hazardous nuclear and chemical wastes. The study of groundwater flow through faults, fissures, and fractures is also of interest to scientists studying the migration of contaminants and to engineers engaged in tunneling through hard rocks for water supply and highway construction projects.

Hard rock hydrogeologists worldwide are therefore divided into two main groups. The first group includes those interested in obtaining groundwater for domestic, irrigational, or industrial use by exploring fractured and permeable zones in a relatively less permeable matrix of hard rock. The second group includes those interested in locating impermeable or least permeable zones for storage of hazardous waste. Ironically, for the first group, even the most permeable zones are often not good enough to yield adequate water supply, while for the second group, even the least permeable zones are often not good enough for safe storage of hazardous waste over a prolonged period.

2. Occurrence of Groundwater

Groundwater under phreatic condition occurs in the mantle of weathered rock, alluvium, and laterite overlying the hard rock, while within the fissures, fractures, cracks, joints, and lava flow junctions within the hard rock the groundwater is mostly under a semiconfined state. Compared with the volume of water stored under semiconfined condition within the body of the hard rock, the storage in the overlying phreatic aquifer is often much greater. In such cases, the network of fissures and fractures serves as a permeable conduit feeding this water to the well.

The recharge to groundwater takes place during the rainy season through direct infiltration into the soft mantle overlying the hard rock and also into the exposed portions of the network of fissures and fractures. In India and other Asian countries, the ratio of recharge to rainfall in hard rock terrain is assumed to be from 3% to 15%. This ratio depends upon the amount and nature of precipitation, the nature and thickness of topsoil and weathered zone, type of vegetation, evaporation from surface of wet soil, profile of underlying hard rock, and the topographical features of the sub-basin. Groundwater flow rarely occurs across the topographical water divides, and each basin or sub-basin can be treated as a separate hydrogeological unit for planning the development of groundwater resources. After the rainy season, the fully recharged hard rock aquifer gradually loses its storage mainly due to pumpage and effluent drainage by streams and rivers. The dry season flow of the streams is thus supported by groundwater outflow. The flow of groundwater is from the peripheral portions of a sub-basin to the central valley portion, thereby causing dewatering of the portions closer to topographical water divides. In many cases, the dug wells and bore wells yielding a perennial supply of groundwater can only be located in the central valley portion.

The average residence time in a sub-basin of about 100 km^2 is up to 5 years or so. The annual recharge is therefore a sizable part of the total storage of the aquifer, and the whole system is very sensitive to the availability of recharge during the rainy season. A couple of drought years in succession can pose a serious problem. The low permeability of the hard rock aquifer is a redeeming feature under such conditions, because it makes small quantities of water available, at least for drinking purposes, in the dug wells or bore wells in the central, valley portion of a sub-basin. If the hard rocks had very high permeability, the groundwater body would have quickly moved towards the main river basin, thereby leaving the tributary sub-basins high and dry. The low permeability in the range of 0.05 to 1.0 meters per day therefore helps in retarding the outflow and regulating the availability of water in individual wells. Therefore, more farmers are able to dig or drill their wells and irrigate small plots of land without causing harmful mutual interference.

3. Groundwater Development

In the highly populated but economically backward areas in hard rock terrain, many governments in the developing countries have taken up schemes to encourage small farmers to dig/drill wells for irrigation. This is especially true for the semi-arid regions where surface water resources are meager. For example, in peninsular India, hard rocks such as granite, gneiss, schist, quartzite, and basalts (Deccan traps) occupy about 1.15 million km^2 of which about 40% is in the semi-arid zone, receiving less than 750 mm rainfall per year. Over 3.5 million dug wells and bore wells are being used in the semi-arid region for irrigating small farm plots and for providing domestic water supply.

The development of groundwater resources for irrigational and domestic use is thus a key factor in the economic thrift of vast stretches of semi-arid, hard rock areas. The basic need of millions of farmers in such areas is to obtain an assured irrigational supply for at least one crop per year and to have a protected, perennial drinking water supply within a reasonable walking distance. The hard-rock hydrogeologists in many developing countries have to meet this challenge to impart social and economic stability to the rural population, which otherwise migrates to the neighboring cities. Providing assurance of at least one crop and rural employment on farms can only solve the problem of exodus of population towards the cities, which is common for many developing countries. Exploration and assessment of groundwater, finding suitable sites for locating dug wells and bore wells, and planning for long-term sustainability of the wells, are the main tasks for achieving this objective.

For promoting large-scale irrigational development from groundwater resources, institutional finance has to be made available to the farmers at lower rates of interest for well digging/drilling. Before selecting an area covering several sub-basins for financing irrigational wells, the primary requirement is the assessment of the available groundwater. In the absence of reliable data on rainfall, evapotranspiration, flood discharge of a stream, and pumpage from existing wells in the sub-basin drained by the stream, assessing the dry season flow and underflow of the stream can achieve a fair estimate of groundwater resource available for new development. This base flow is supported by the effluent drainage from groundwater in the sub-basin, and a part of it can be tapped by the proposed new wells. Once the technical feasibility is ascertained, the financing institutions or the banks need to estimate the economic viability of an average individual well, based on the average yield of the well in different cropping seasons, supporting a suitable cropping pattern. The total incremental income from such a cropping pattern should enable the farmer to repay the loan with interest, over an average period of 7 to 9 years. Some of the banks also make provision for insurance of failed wells.

Groundwater development in a sub-basin results in increased pumpage because of the new wells, a lowering of the water table, and hence the reduction of the effluent drainage from the sub-basin. Such development in several sub-basins draining into a main river basin reduces the surface flow and the underflow of the river, thereby affecting some of the surface water schemes depending on the river flow. In order to minimize such interference, it is advisable to adopt water (and soil) conservation measures and recharge augmentation techniques in the sub-basins, simultaneously with the groundwater development programs.

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Biographical Sketch

Shrikant Daji Limaye received his Ph.D. in 1980, from the University of Poona, India. His thesis was entitled "Some Aspects of Integrated Groundwater Development." In 1969 he was awarded a UNESCO sponsored Post-Graduate Diploma in Water Resources, by the Hebrew University of Jerusalem, Israel. In 1962 he received a Master of Technology (M.Tech.) in Exploration Geophysics from the Indian Institute of Technology, Kharagpur, India, and in 1959 a Bachelor of Engineering, from the University of Poona.

Dr. Limaye has been in the field of groundwater for over 40 years. He is currently Director of the Groundwater Institute, a position he has held for the past 11 years. The Groundwater Institute is a private trust Institute (non-government, non-university) devoted to groundwater exploration, assessment, and sustainable development for small farmers, farmer-cooperatives and periurban settlements. The institute also specializes in conjunctive use of surface water and groundwater; recharge augmentation, and watershed development.

Dr. Limaye was elected as President of the Association of Geoscientists for International Development (AGID) for the Term 1996–2000, at the General Body meeting of AGID in Beijing, and was elected as Vice President (Asia) of the International Association of Hydrogeologists (IAH) for the term 2000–2004. He is the recipient of a One Year Research Associate Award from the International Development Research Centre (IDRC), Ottawa, Canada, and is a Fellow and Chartered Engineer, Institution of Engineers (India). Dr. Limaye is a member of the Technical Evaluation Committee for Water Resources Research Projects, submitted by NGOs to the Department of Science and Technology, Government of India, New Delhi.

Dr. Limaye has personally presented over 35 technical papers to international conferences/symposia on water resources development, held in countries such as Australia, Canada, China, Denmark, Germany, Norway, Italy, Pakistan, Russia, Sri Lanka, Sweden, the UK, the USA, Venezuela, and Zimbabwe. He has worked as a consultant on projects of the Asian Development Bank, the World Bank, and FAO, in Bangladesh, Nigeria, and Laos respectively.