

Sustainable Ground Water Development in Hard Rock Aquifers in Low-Income Countries and the Role of UNESCO-IUGS-IGCP Project “GROWNET”

Dr. Shrikant Daji LIMAYE

Project Leader, UNESCO-IUGS-IGCP Project GROWNET (website: www.igcp-grownet.org)

Director, Ground Water Institute, Pune, India

Past President, Association of Geoscientists for International Development (AGID)

Past Vice-President (Asia) & Honorary Life Member, International Association of Hydrogeologists (IAH)

Address: 2050, Sadashiv Peth, Pune 411 030, INDIA (E-mail: limaye@vsnl.com)

Abstract

Hard rock aquifers for the purpose of this Paper mean the non-carbonate, fractured rock aquifers in the terrain covered by crystalline basement complex, metamorphic rocks and also by extensive effusive volcanic rocks like the basalts of western India (Deccan traps)

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

- 1. A topographical basin or sub-basin generally coincides with ground water basin. In this, the ground water resources tend to concentrate towards the central valley portion, closer to the main stream and its tributaries.*
- 2. Depth of ground water occurrence, in useful quantities, is usually limited to a hundred metres or so.*
- 3. 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.*
- 4. 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.*
- 5. Only a modest quantity of ground water, in the range of one cu.m. and one hundred cu.m. or so per Day, is available at one spot. Drawdown in a pumping dug well or bore well is often almost equal to the saturated thickness of the aquifer.*

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

It should, however, be remembered that for the millions of farmers in developing countries, having their small farms in the barren landscape of fractured hard rock terrain, whatever small supply available from these poor aquifers is the only hope 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.

This Paper discusses the occurrence of ground water and the precautions for sustainable development of ground water in arid and semi-arid regions, in view of the forthcoming climatic changes. It emphasizes the need for recharge augmentation hand-in-hand with development of new wells, so that the new development does not harm the traditional practices. In India, the neglect of recharge augmentation has caused lowering of water table and drying-up of old dug-wells of 12m to 15 m depth, which used to provide irrigational and drinking water supply for last several centuries. In Iran, many Qanats have dried

up because of lowering of water table due to heavy pumping of ground water from newly developed deep tube-wells in their vicinity. The goal in many countries has, therefore, shifted from ground water development to ground water management which includes management of the quantity on Supply side and Demand side and also the management of ground water quality, especially with respect to pollution and salt water intrusion. Pollution of ground water in urban environment is becoming a cause of worry because in many developing countries there is a heavy migration of population from rural areas to urban centers and providing safe quality of drinking water to this population and managing the waste water generated in the cities and towns, is a major problem.

The role of UNESCO-IUGS-IGCP Project GROWNET (Ground Water Network for Best Practices in Ground Water Development in Low Income Countries) is also described towards the end of this Paper. The Author is the Project Leader for GROWNET and has an experience of 52 years in ground water development in semi-arid, hard rock areas.

1.0 Occurrence of Ground Water in Hard Rocks

In hard rock terrains, ground water 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, ground water is mostly under semi-confined state. Compared to the volume of water stored under semi-confined 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.

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The recharge to ground water 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 between 3 to 15%, depending upon the amount and nature of precipitation, the nature and thickness of top soil and weathered zone and the topographical features of the sub-basin. Ground water 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 ground water 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 ground water outflow. The flow of ground water 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, a dug well or a bore well yielding perennial supply of ground water can only be located in the central valley portion.

2.0 Ground Water Development

Development of a natural resource like ground water is an activity towards its optimum utilization for the benefit of mankind. 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 sq. kms area out of which about 40% is in 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. Dug wells in hard rock aquifers are usually 3 to 5 m in diameter and 10 to 15 m in depth. Bore wells are 100 mm to 150 mm in diameter and are 80 to 100 m deep.

3.0 Exploration

Exploration for locating sites for well digging and drilling in hard rock terrain is vitally important for successful completion of irrigation or drinking water supply projects, because hard rock aquifers are not extensive and their properties vary in short distances. Basic exploration is done by collecting topographical and geological maps, air photos and satellite imageries, if available, and by conducting a hydrogeological survey during which the following observations are made and information collected:

1. Inventory of existing wells. Their depth, diameter and yield and type of strata met with. Level of water table. Area irrigated by each well. Type of pump and pumping schedule. Seasonal fluctuation in water table.
2. Rainfall and drainage pattern.
3. Lithological units met with in wells. Their strike and dip in sedimentary strata. The thickness of soft overburden and its relation to topography. The extent of fissuring in hard rock and its relation to topography.
4. The sandy or rocky nature of the stream or river bed. Whether the stream is seasonal or perennial. The prospects of attracting influent seepage from the stream to a pumping well on the bank.
5. Shifting and meandering of river. Erosional or depositional features on river bank. Evidence, if any, of rejuvenation.
6. Locations and discharge of natural springs, if any, in the area.
7. Locations of surface water reservoirs, if any in the area. Possibility of receiving recharge during the dry season from surface water reservoirs and/or the irrigational canals shooting off from the reservoir. If the canals are lined, the possibility of getting recharge from deep percolation below root zone, in the irrigated area.
8. The occurrence of dykes, pegmatite veins etc. in the area and their nature as ground water conduits or barriers. Whether there are any good wells upstream from the dyke. Any preferred direction of fracture orientation in the area as observed from rock exposures and strata met with in dug wells.
9. Correlation, if any, between the lineaments observed in air photos or satellite imageries and the locations of successful wells in the area or patches of dense natural vegetation in an otherwise sparsely vegetated landscape.
10. Variations, if any, in the quality of ground water along its general flow direction.
11. Whether there are any erratically successful or erratically failed wells, which do not fit into the conceptual model of ground water occurrence in the area. Such wells indicate discontinuity and lateral variation in the aquifer.

Such observations and information is useful in delineating promising zones for ground water development in a sub-basin. Geophysical resistivity or electromagnetic surveys can then be carried out in these zones for selection of suitable well sites. Due to lateral variations in the strata, Wenner profiling is more useful than Wenner or Schlumberger sounding. Profiling is done with electrode spacing between 20 to 50 metres, for locating a fractured, low resistivity zone in

the hard rock covered by a soft mantle. For finding out the fracture orientation, azimuthal resistivity survey can be carried out over the low resistivity zone. In this survey, resistivity readings are taken around one central spot, with the same electrode configuration but in different directions. The direction of fractures is parallel to the direction of highest resistivity, due to the paradox of resistivity anisotropy.

4.0 Recharge Augmentation

With the increase in pumpage due to new wells in a sub-basin, the water table gets depleted and the effluent drainage from the sub-basin gets reduced. In the hard rock areas, the total storage of ground water and average residence time both being small, the system is much more sensitive to variations in pumpage and recharge compared to a similar system in alluvial or carbonate aquifer area. As mentioned earlier, it is therefore, advisable to start soil and water conservation and recharge augmentation activities along with the ground water development schemes. Some of these activities such as hill slope trenching, contour bunding, afforestation, gully plugging etc., are useful in increasing the infiltration to ground water body during the rainy season. But the geometrical factors of the sub-basin and the thickness and storativity of weathered rock and fractured rock set a limit to the recharge that can be accepted in the rainy season.

Many developing countries have a well defined rainy season in the year which is followed by a prolonged dry period. In such a climate, a sizable portion of the recharge received in rainy season may leave the sub-basins by the way of effluent stream flow and ground water outflow, within the first few months of the dry season. Water scarcity may thus occur towards the later months of the dry period, which in the Monsoon climate is the summer season. It is therefore necessary to undertake activities which would retard the ground water outflow and which would cause recharge to ground water body during the earlier months of the dry season.

5.0 Sustainability and Pumpage Control

Sustainable development is achieved when the quality and quantity of water available from the wells remains unaffected over the years. In hard rock areas, ground water or the resource itself is modest in quantity, erratic in occurrence and sensitive to changes in pumpage and recharge. It is therefore not easy to ensure sustainability of all the wells over decades of years because many farmers go for well digging/drilling each year and the pumpage in a sub-basin increases year by year. Some of the sub-basins get over developed and the yields from the wells decline due to mutual interference and general depletion in water table level. Under such a condition, the drinking water supply wells need to be protected first. This is done either by preventing construction of new wells within a specified distance from a drinking water supply well or by giving the Government authorities a right to acquire any private well in the vicinity, after paying due compensation, for providing water supply to the village.

Pumpage control is a negative way of management but when it has to be imposed, it should only be through mutual monitoring by farmers or by local council at the village level. The concept of sustainability in such a case may consider only a period of about 7 to 9 years in which a farmer usually recovers his investment made in constructing the well. The owners of high yielding wells should be the first ones to cut down on their pumpage and pump only an equitable share, so that other farmers may also dig/drill new wells. This is better done through persuasion and social pressure rather than through any rigid legislation. In complex, anisotropic and discontinuous hard

rock aquifers, any rigid legislation is technically unsound and sociologically unjust. It may just lead to endless and futile court battles.

6.0 UNESCO-IUGS-IGCP Project GROWNET

The project “GROWNET – (Ground Water Network for Best Practices in Ground Water Management in Low-Income Countries)” was approved by the UNESCO-IUGS-IGCP in the year 2005, with the Author of this Paper as the Project Leader. The website **www.igcp-grownet** of GROWNET project lists several best practices which are connected to the development, utilization and sustainable management of the resource. The website has so far received over 7,100 visits and is very popular amongst Government Departments, NGOs, University Students and Staff members, Educated farmers and citizens who are interested in sustainable ground water development.

7.0 Conclusions

The policy for sustainable groundwater management in hard rock aquifer regions should pay attention to the following points, for achieving sustainable development:

1. Economical and efficient use must be made of the ground water pumped from the aquifers.
2. Watershed development through forestation and soil and water conservation programs should be taken up on priority basis so as to mitigate the effects of impending climate change and ensure recharge augmentation. Percolation tanks should be constructed at suitable sites.
3. Conjunctive use of surface water and groundwater should thus be practiced.
4. Land use planning for a river basin is necessary so as to control the pollution of surface water and groundwater.
5. It is necessary to promote food crops that give more calories per cubic meter and of cash crops that give more value per cubic meter of water pumped from the aquifer.
6. Involvement of women should be encouraged in planning, execution and management of village drinking water supply schemes and in schemes of promoting small scale irrigation by well digging/drilling.
7. Achievement of pumpage control in overexploited watersheds may only be possible through the recommendations by village councils and through social pressure on any farmer who over-exploits the resource.

References

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