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Importance of Percolation Tanks for Water Conservation for Sustainable Development of Ground Water in Hard-Rock Aquifers in India

Shrikant Daji Limaye

UNESCO-IUGS-IGCP Project 523 "GROWNET"

International Association of Hydrogeologists (IAH)

¹*Ground Water Institute*

²*Association of Geoscientists for International Development (AGID)*

³*International River Foundation, Brisbane,*

¹*India*

²*UK*

³*Australia*

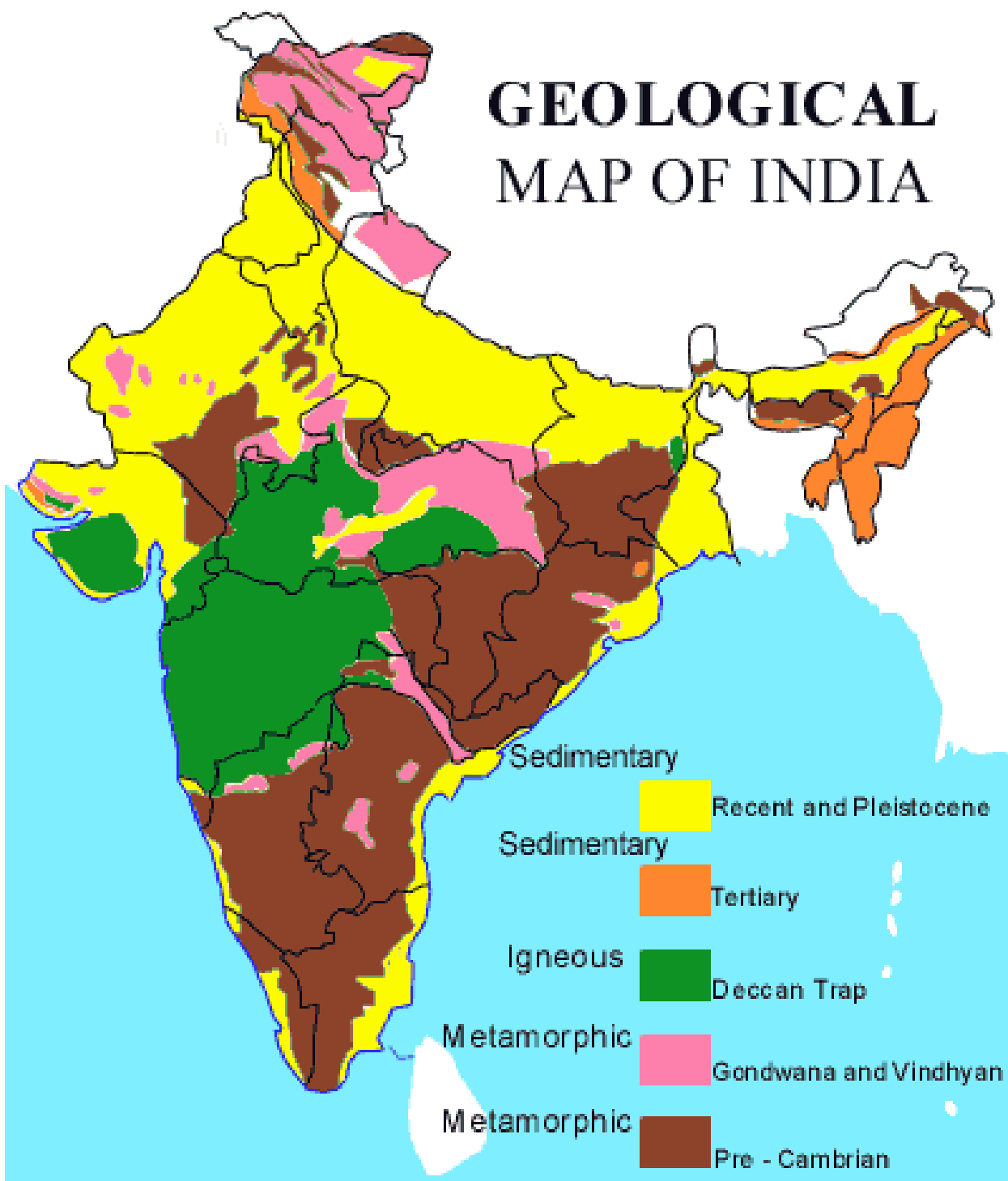
1. Introduction

Development of a natural resource like ground water is a concerted activity towards its sustainable use for human benefit. The concept of sustainable use is related to various factors like the volume of water storage in the aquifer, annual recharge or replenishment, volume of annual pumpage for the proposed use, benefit/cost ratio of the proposed use, and environmental impacts of the proposed use.

Hard rock aquifers in this paper mean the non-carbonate, fractured rocks like the crystalline basement complex and metamorphic rocks, which cover an area of about 800,000 sq. Kms. in central and southern India. Basalts of western India also known as the Deccan traps of late Cretaceous to early Eocene period are also included as a special case. Deccan traps comprise hundreds of nearly horizontal, basaltic lava flows in a thick pile and cover around 500,000 sq. kms of western India. (Fig. 1a and 1b) This pile was not tectonically disturbed after consolidation and a hand specimen does not show any primary porosity due to the non-frothy nature of the lava. (Adyalkar & Mani 1971) Hydrogeologically, the Deccan traps have low porosity and are therefore, akin to fractured hard rock aquifers.

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

1. A topographical basin or a sub-basin generally coincides with ground water basin. Thus, the flow of ground water across a prominent surface water divide is very rarely observed. In a basin, the ground water resources tend to concentrate towards the central portion, closer to the main stream and its tributaries.
2. The depth of ground water occurrence, in useful quantities, is usually limited to a hundred meters or so.



Note: Basement Complex (Granite, Gneiss, and other Metamorphic rocks) is shown in brown color. Basaltic area is shown in green. Black lines show State boundaries. The state of Maharashtra on the western coast is almost covered by Basalt or Deccan Trap (Green color). Peninsular India is mostly covered by Basalt and Basement Complex.

Fig. 1(a). Geological Map of India showing Basement Complex and Basalts of Peninsular Region. (Scale: 1cm = 200 km).



Fig. 1(b). Nearly horizontal lava flows comprising the Deccan Traps or Basalts of Western India. Location: Western Ghat hills between Pune and Mumbai, Maharashtra State.

3. 3. 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 well, a wide range of values of S and T is obtained. The applicability of mathematical modeling is limited to only a few simpler cases within a watershed. But such cases do not represent conditions over the whole watershed.
4. 4. The phreatic aquifer comprising 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.
5. 5. Only a modest quantity of ground water, in the range of one cu. meter up to a hundred cu. meters 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.

Ground water development in hard rock aquifer areas in India and many other countries has traditionally 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 the difficulties in exploration and quantitative assessment of the resource.

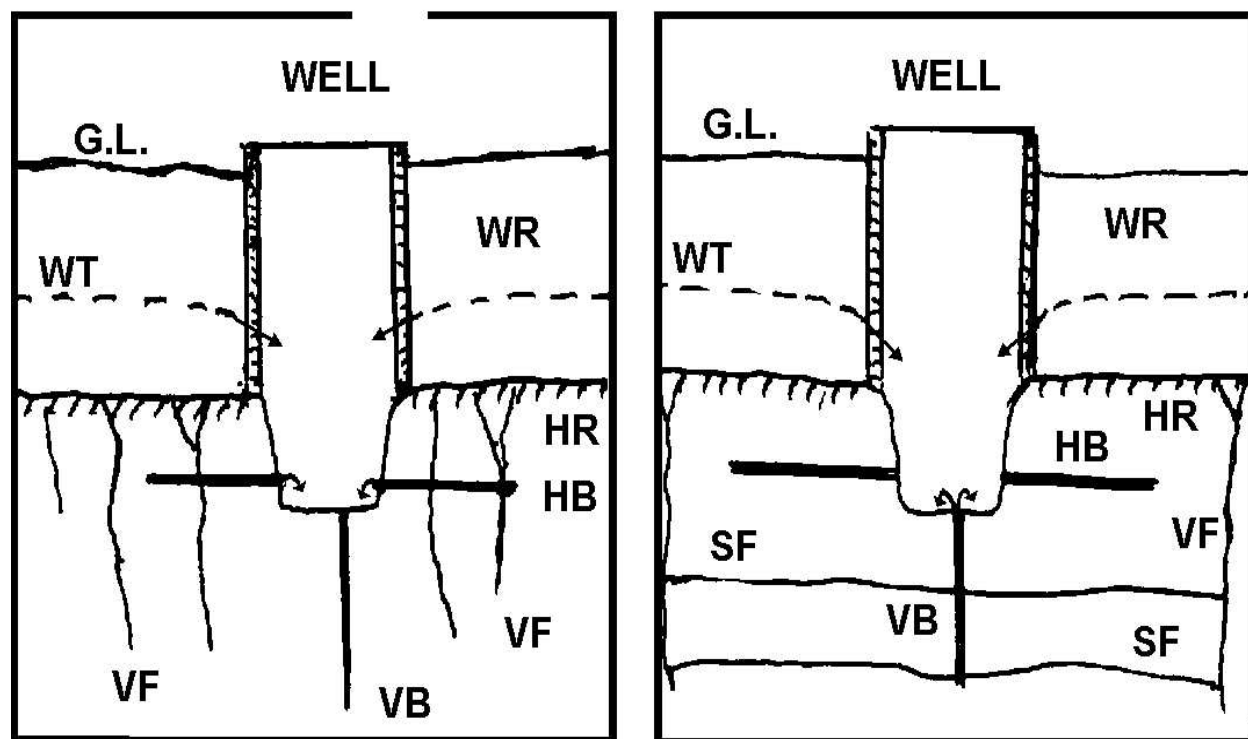
It should, however, be realized that millions of farmers in developing countries have their small farms in fractured basement or basaltic terrain. Whatever small supply available from these poor aquifers is the only hope for these farmers for upgrading their standard of living by growing irrigated crops or by protecting their rain-fed crops from the vagaries of Monsoon rainfall. It is also their only source for drinking water for the family and cattle. In many developing countries, like in India, hard rock hydrogeologists have, therefore, an important role to play.



Fig. 2. Red bole (inter-trappean bed) sandwiched between hard, fractured basalt flows. (Exposure seen in road-side cutting on Pune-Bangalore highway Pune District, Maharashtra State.)

2. Occurrence of ground water

Ground water under phreatic condition occurs in the soft mantle of weathered rock, alluvium and laterite overlying the hard rock. Under this soft mantle, ground water is mostly in semi-confined state in the fissures, fractures, cracks, and joints. (Deolankar 1980) In basaltic terrain the lava flow junctions and red boles sandwiched between two layers of lava flows, also provide additional porosity (Fig 2). The ratio of the volume of water stored under semi-confined condition within the body of the hard rock, to the volume of water in the overlying phreatic aquifer depends on local conditions in the mini-watershed. Dug-cum-bored wells tap water from the phreatic aquifer and also from the network of fissures, joints and fractures in the underlying hard rock. (Fig 3 A and Fig 3B).



GL - Ground Level, HB - Horizontal Bore, HR - Hard Rock, SD - Sheet Fracture or joint, VB - Vertical Bore, VF - Vertical Fracture, WR - Weathered rock, WT - Water Table.

Fig. 3A. and 3B. Dug cum Bored Wells

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 in Monsoon climate, the ratio of recharge to rainfall in hard rock terrain is assumed between 3 to 15%. (Limaye S.D & Limaye D.G. 1986) 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, the topographical features of the sub-basin and the status of soil and water conservation activities adopted by villagers. 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 de-watering of the portions closer to topographical water divides. In many cases, the dug wells and bore wells yielding perennial supply of ground water can only be located in the central valley portion.

The annual recharge during Monsoons being a sizable part of the total storage of the aquifer, the whole system in a sub-basin or mini-basin, is very sensitive to the availability of this recharge. A couple of drought years in succession could pose a serious problem. The low permeability of hard rock aquifer is a redeeming feature under such conditions because it makes small quantities of water available, at least for drinking purpose, in the dug wells or bore wells in the central portion of a sub-basin. If the hard rocks had very high permeability,

the ground water 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 meter per day thus helps in retarding the outflow and regulating the availability of water in individual farm wells. More farmers are thus able to dig or drill their wells and irrigate small plots of land without causing harmful mutual interference.

3. Ground water development

In the highly populated but economically backward areas in hard rock terrain, Governments in many developing countries have taken up schemes to encourage small farmers to dig or drill wells for small-scale 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 (800,000 sq kms) and basalts (Deccan traps- 500,000 sq kms) occupy about 1.30 million sq. kms area out of which about 40% is in semi-arid zone, receiving less than 750 mm rainfall per year. Over 4.00 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.

Development of ground water 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 supply for protective irrigation of at least one rain-fed 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. The problem of rapid urbanization by exodus of rural population towards the cities, which is common for many developing countries, can only be solved by providing assurance of at least one crop and rural employment on farms.

Ground water development in a sub-basin results in increased pumpage and lowering of the water table due to the new wells, resulting in the reduction of the effluent drainage from the sub-basin. Such development in several sub-basins draining into the main river of the region reduces the surface flow and the underflow of the river, thereby affecting the function of the surface water schemes depending on the river flow. In order to minimize such interference, it is advisable to augment ground water recharge by adopting artificial recharge techniques during rainy season and also during dry season. The measures for artificial recharge during Monsoon rains include contour trenching on hill-slopes, contour bunding of farms, gully plugging, farm-ponds, underground stream bunds, and forestation of barren lands with suitable varieties of grass, bushes and trees. Artificial recharge in dry season is achieved through construction of percolation tanks.

However, increase in pumpage takes place through the initiative of individual farmers to improve their living standard through irrigation of high value crops, while recharge augmentation is traditionally considered as Government's responsibility and always lags far behind the increase in pumpage. In many parts of the world, particularly in developing countries, groundwater is thus being massively over-abstracted. This is resulting in falling water levels and declining well yields; land subsidence; intrusion of salt water into freshwater supplies; and ecological damages, such as, drying out wetlands.

Groundwater governance through regulations has been attempted without much success, because the farmers have a strong sense of ownership of ground water occurring in their

farms. Integrated Water Resources Development (IWRM) is being promoted as a policy or a principle at national and international levels but in practice at field level, it cannot be attained without cooperation of rural community. NGOs sometimes play an important role in educating the villagers and ensure their cooperation.

4. Importance of dry season recharge

During the rainy season from June to September the recharge from rainfall causes recuperation of water table in a sub-basin from its minimum level in early June to its maximum level in late September. This is represented by the equation:

$$P = R + ET + r$$

Where P is the precipitation, R is surface runoff, ET is evapo-transpiration during the rainy season and r is the net recharge, represented by the difference between the Minimum storage and Maximum storage in the aquifer. However, after the aquifer gets fully saturated, the additional infiltration during the Monsoons is rejected and appears as delayed runoff. During the dry season, depletion of the aquifer storage in a sub-basin, from its maximum value to minimum value, is represented by the following equation:

$$\begin{aligned} & \text{(Aquifer storage at the end of rainy season i.e. Maximum storage)} = \\ & \text{(Aquifer storage at the end of summer season, i.e. Minimum storage)} + \\ & \text{(Pumpage, mainly for irrigation, during the dry season from dug wells \& bore wells)} + \\ & \text{(Dry season stream flow and underflow supported by ground water)} - \\ & \left(\text{Recharge, if any, available during the dry season, including the return flow from} \right. \\ & \left. \text{irrigated crops} \right) \end{aligned}$$

The left-hand side of the above equation has an upper limit, as mentioned above. On the right-hand side, the minimum storage cannot be depleted beyond a certain limit, due to requirement for drinking water for people and cattle. Dry season stream flow and underflow supported by ground water have to be protected, as explained earlier, so that the projects depending upon the surface flow of the main river are not adversely affected. Any increase in the pumpage for irrigation during dry season due to new wells must therefore be balanced by increasing the dry season recharge.

The best way to provide dry season recharge is to create small storages at various places in the basin by bunding gullies and streams for storing runoff during the rainy season and allowing it to percolate gradually during the first few months of the dry season. Such storages created behind earthen bunds put across small streams are popularly known as percolation tanks. (Fig. 4 and Fig 5). In semi-arid regions, an ideal percolation tank with a catchment area of 10 sq. kms. or so, holds maximum quantity by end of September and allows it to percolate for next 4 to 5 months of winter season. Excess of runoff water received in Monsoon flows over the masonry waste weir constructed at one end of the earthen bund. By February or March the tank is dry, so that the shallow water body is not exposed to high rates of evaporation in summer months. (Fig.6) Ground water movement being very slow, whatever quantity percolates between October and March, is available in the wells on the downstream side of the tank even in summer months till June or the beginning of next

Monsoon season. Irrigation of small plots by farmers creates greenery in otherwise barren landscape of the watershed. (Fig.7). Studies carried out in granite-gneiss terrain have indicated that about 30% of the stored water in the tank percolates as recharge to ground water in the dry season. The efficiency is thus 30%. In basaltic terrain, if the tank is located at suitable site and the cut-off trench in the foundation of tank-bund does not reach up to the hard rock, higher efficiencies up to 70% could be obtained. (Limaye D.G & Limaye S D. 1986) However, more research is required for estimation of the impact of percolation tanks in recharge augmentation. In the state of Maharashtra in western India, over 10,000 percolation tanks have been constructed so far. (DIRD website, 2011) They are beneficial to the farmers and are very popular with them.

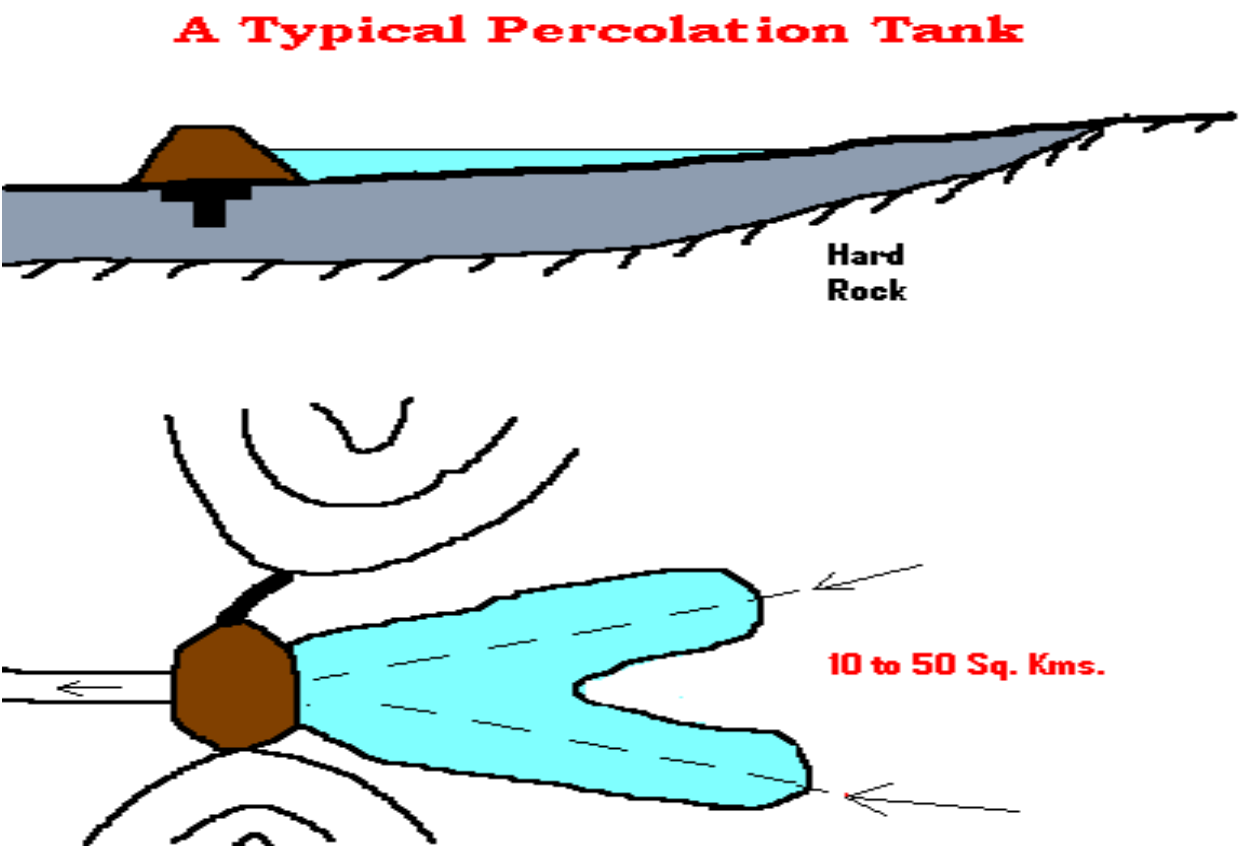


Fig. 4. Cross section and plan of a typical percolation tank on a stream between two hillocks. Hillocks are represented by black contours. Earthen Bund of the tank is shown in brown. Cut-off trench below the bund is in black and accumulated rain water is in pale blue color.



Fig. 5. Stone Pitching on the face of the earthen bund of a percolation tank under construction. Photo from village Hivre Bazar, District: Nagar, Maharashtra state.



Fig. 6. A percolation tank about to get dry towards beginning of summer. Location: Village: Ralegan Siddhi, District: Nagar, Maharashtra State.



Fig. 7. Greenery crated within a dry, semi-arid watershed with the help of water conservation, farm ponds and percolation tank. The open well has shallow water table even in summer. A low cost centrifugal pump would soon be installed for small scale irrigation. (Location: Village Hivre Bazar. Dist: Nagar, Maharashtra State)

The initial efficiency of a percolation tank reduces due to silting of its bottom by receiving muddy runoff from the watershed. If the watershed is well-forested and has a cover of grass, bushes and crops, the silting is minimal. But in an average of 5 to 6 Monsoon seasons the tank bed accumulates about 0.20 to 1.00 meters of silt. Silt reduces the storage capacity of the tank and also impedes the rate of vertical flow of recharge because of its low permeability. The efficiency gets reduced due to silting and de-silting of tank bed when it dries in summer, becomes necessary. (Limaye S D. 2010).

Another type of recharge available during the dry season is the return flow or the percolation below the root zone of crops, from irrigated farms. This return flow to ground water is usually estimated at about 25% to 30% of the volume of ground water pumped in dry season and applied for irrigation. However, due to increasing popularity of more efficient irrigation methods like sprinkler or drip systems, this type of recharge has a declining trend.

5. Conclusions

A watershed is the meeting point of climatology & hydrology. It is therefore, necessary to manage our watersheds so as to absorb the climatic shocks likely to come from the erratic

climatic patterns expected in near future. This can be done only through practicing soil and water conservation techniques for artificial recharge during rainy season and through construction of small percolation tanks for artificial recharge during the dry season.

Basin or Sub-Basin management begins with soil and water conservation activities taken up with people's active participation in several sub-basins within a large basin. This improves the shape of hydrograph of the stream or river in the basin, from a 'small time-based and sharp-peaked hydrograph' to a 'broad time-based and low-peak hydrograph'. Such a change also increases ground water recharge.

Small water storages or tanks created in the sub-basins by bunding streams and gullies, store runoff water during the Monsoon season and cause recharge to ground water during the next few months of dry season. The residence time of water in the basins is thus increased from a few months to a few years and the percolated water is available in the wells even during the summer season of a drought year.

After a few years of operation, silting of the tank bed reduces the volume of water stored and also the rate of vertical infiltration. Regular desilting of tanks by local people is, therefore, advisable.

A national policy for afforestation of degraded basins with proper species of grass, bushes and trees should be formulated. Afforestation with eucalyptus trees should not be encouraged in low rainfall areas as this effectively reduces ground water recharge. The main aim of forestation of a degraded watershed with local species of hardy trees, grasses etc. should be to conserve soil, reduce velocity of runoff water, promote recharge to ground water and increase the biomass output of the watershed. .

Involvement of NGOs should be encouraged in forestation schemes and soil & water conservation programs so as to ensure active participation of rural community in recharge augmentation. NGOs also motivate the farmers to maintain the soil and water conservation structures put in by Government Departments so as to ensure long-term augmentation of recharge to ground water. Along with such management on supply side, demand management is also equally important. NGOs play a significant role in promoting the use of efficient irrigation methods and selection of crops with low water requirement.

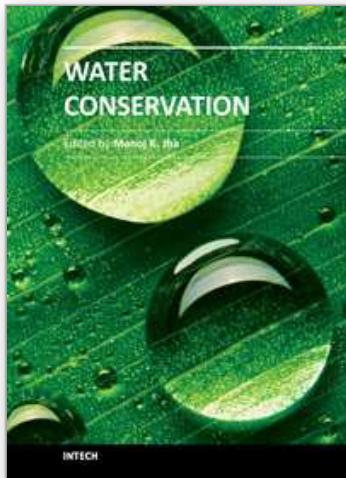
The website www.igcp-grownet.org of the UNESCO-IUGS-IGCP Project GROWNET (Ground Water Network for Best Practices in Ground Water Management in Low-Income countries) gives several best practices including soil and water conservation, recharge augmentation etc. for sustainable development of ground water. The author of this Paper is the Project Leader of GROWNET. The reader is advised to visit the website for detailed information.

Although the discussion in the Paper refers to hard rock terrain in India, it would be equally applicable to many other developing countries, having a similar hydro-geological and climatic set-up.

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Water is an essential and basic human need for urban, industrial and agricultural use. While an abundance of fresh water resources is available, its uneven distribution around the globe creates challenges for sustainable use of this resource. Water conservation refers to an efficient and optimal use as well as protection of valuable water resources and this book focuses on some commonly used tools and techniques such as rainwater harvesting, water reuse and recycling, cooling water recycling, irrigation techniques such as drip irrigation, agricultural management practices, groundwater management, and water conservation incentives.

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Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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