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

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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. 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. 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, is recently promoted by the prospects of using these low permeability rocks for the storage of hazardous nuclear and chemical wastes. The study of ground water flow through faults, fissures and fractures is also of interest to scientists studying the migration of contaminants. Hard rock hydrogeologists, the world over, are therefore divided into two main groups: Those interested in obtaining ground water for domestic, irrigational or industrial use by exploring fractured and permeable zones in a relatively less permeable matrix of hard rock and those interested in locating impermeable or the least permeable zones for storage of hazardous nuclear 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 nuclear waste over a prolonged period of a few hundred years.

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.

Keywords: *Ground water development, Hard rock aquifer, Low income countries, "GROWNET"*

1. Occurrence of Ground Water in Hard Rocks

The most significant features of the hard rock aquifers, especially of those in central and peninsular India, 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 meters 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

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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.

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. [4]

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.

The average residence time in a sub-basin of about 100 sq.kms area is up to five years. The annual recharge is thus a sizable part of the total storage of the aquifer and the whole system is very sensitive to the availability of recharge during rainy season. A couple of drought years in succession can 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 central valley portion of a sub-basin. If the hard rocks had very high permeability, ground water body would have quickly moved towards the main river basin, thereby leaving the sub-basins high and dry. The low permeability in the range of 0.05 to 1.0 meters per day thus helps in retarding the outflow and regulating the availability of water in individual wells. More farmers are able to dig or drill their wells and irrigate small plots of land without causing harmful mutual interference.

2. 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.

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 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 would otherwise migrate to the neighbouring cities. Exploration and assessment of ground water, finding suitable sites for locating dug wells and bore wells and planning for long term sustainability of the wells, are the main tasks under these circumstances.

For promoting large scale irrigational development from ground water resources, institutional finance has to be made available to the farmers at concessional 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 ground water. In absence of reliable data on rainfall, evapo-transpiration, flood discharge of a stream and pumpage from existing wells in the sub-basin drained by the stream, a fair estimate of ground water resource available for new development can be made by assessing the dry season flow and underflow of the stream. This base flow is supported by the effluent drainage from ground water 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.

Ground water development in a sub-basin results in increased pumpage due to the new wells, lowering of the water table and hence in 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 conservation and recharge augmentation techniques in the sub-basins, simultaneously with the ground water utilization programs.

3. Types of Wells

For obtaining shallow, phreatic ground water in low permeability hard rock aquifers, dug wells and dug-cum-bored wells are commonly used. A dug well offers more area for inflow of ground water into it and also provides a sizable storage for water accumulation. The volume of rock excavated while constructing a dug well is often much more than the REV (Representative Elemental Volume) of the fractured rock aquifer and there are fair chances of tapping water bearing, vertical and horizontal fractures and fissures in the excavation, especially if the site for the well is carefully selected. Otherwise, these fractures may be dry or may bear water only for a few months of the year. [3]

A typical dug well has a diameter of 3 to 8 meters and depth of 5 to 15 meters. It usually penetrates through the weathered mantle and goes a few meters into the underlying fractured rock. A retaining wall of stone or brick masonry is required to support the upper portion of the dug well, excavated in soil, sub-soil and highly weathered rock overlying the hard rock. The masonry wall is provided with weep holes, especially in its bottom part so as to allow inflow of phreatic water into the well. In areas where hard rock is covered by laterite or weathered zone rich in lime nodules, a retaining wall may not be necessary to support the excavation. Some of the deeper dug wells are dug through the weathered mantle and the fissured rock, into the massive hard rock below, so as to provide adequate storage for water flowing into the well during a period of 8 to 10 hours. This way, the farmer can conveniently pump the stored water, once in the morning and once in the evening, by using a low-cost centrifugal pump-set. It is customary to provide two or three platforms at different levels inside the well, for installing the pump-set according to the water levels in different seasons. Foot valve of the pump is kept in a small pit excavated in the well bottom, so as to facilitate emptying of the well. On shallow wells, animal drawn devices or human powered water wheels can also be employed to lift water for irrigation of small plots.

Horizontal bores can be drilled radially outward from a dug well, at various level below the water table, so as to increase its yield. Horizontal bores of 25 mm to 75 mm dia. and of lengths upto 10 to 15 metres are drilled in laterite, alluvial cover and weathered rock overlying the fractured hard rock, manually or with the help of drilling machine. In very soft strata such bores have to be supported by inserting slotted casing pipes. Such bores increase the effective diameter of the dug well, without a proportionate increase in the cost. Horizontal boring in fractured hard rock is done to tap more water from the neighbouring vertical fissures and fractures. Such bores usually go radially outward from the wet patches or mouths of springs, issuing into the dug well from the fractured strata.

Vertical bores of 100 mm to 150 mm dia and depths upto 50 to 60 meters are drilled in the bottom of the dug wells to tap semi-confined water in the deeper horizontal or sub-horizontal fractures, joints or flow junctions. Water from such bores rises over the bottom of the dug well and gets collected into it, if the bottom of the dug well is about 5 meters below the water table. The centrifugal pump installed on the dug well can then pump this water out. If water from the vertical bore does not rise into the well, a separate pump is required. A submersible pump can be installed if the yield from the bore is above 4 to 5 cu.m. per hour and the water directly taken for irrigation, rather than storing it in the dug well. Submersible pumps being expensive, `low water level` guards are installed to stop the pump when the water level reaches near the top of the pump. This prevents dry running of the pump. Restarting of the pump can be done by using a timer switch on the control panel or by using a `high water level` sensor in the bore. If the yield is small, a Jet or Ejector pump is used to pump out water from the bore. The water is stored in the dug well till a sizable quantity accumulates in 8 to 10 hours and then pumped out in 2 to 3 hours, by the centrifugal pump installed on the dug well. In this case, a casing pipe of about 3 to 4 meters length is taken and half of it is inserted into the bore and the remaining half sticks out over the well bottom. Cement concrete is put around this pipe so that the water accumulating in the dug well does not go back into the bore.

It is a common practice to drill horizontal and vertical bores below the water table in a dug well.

In areas where vertical fractures, fissures and joints occur in the vicinity of a dug well, horizontal bores are more successful, while in areas where horizontal or sub-horizontal joints, bedding planes, cleavages, flow junctions or fractures are frequent, vertical bores would be more successful.

The cost of a dug well of about 6 m dia and of 15 m depth in India and other Asian countries like Nepal, Pakistan and Sri Lanka, would be around US $3,000. In

African countries like Kenya or Zimbabwe, the cost would be almost doubled due to scarcity of trained laborers. In the soft strata met with in the beginning, the excavation is cheaper but a masonry wall has to be built to support the strata. In the underlying hard fractured rock, the excavation is expensive because dynamite blasting is often necessary. But this portion of the dug well does not need a retaining wall. When blasting in the fractured rock for well excavation below the water table level, it is advisable to blast only one to two holes at a time, instead of blasting simultaneously, all the 40 or 50 holes drilled in the bottom of the excavation. If all the holes are simultaneously blasted, the fracture network often receives a heavy shock and the yield of water into the dug well gets reduced. The cost of drilling horizontal bores is around US $ 2 to 3 per meter while vertical bores cost around US $ 4 to 5 per meter, in India.

Other types of dug wells include large diameter (10 to 20 meters) shallow dug wells of 4 to 5 meters depth, excavated in coastal areas for skimming fresh water floating over saline water and rectangular `trench` wells of 1 to 2 meters width and 10 to 50 meters length excavated at right angle to the direction of ground water flow. Such a `trench` well dug across the bed of a stream or river, at a carefully selected location, taps large quantity of the underflow, even after the stream dries up. It is customary to fill back the excavation, creating an inverted filter, with boulders in bottom, gravel in the middle and coarse sand in the upper portion. The porous and permeable trench thus created across the river bed in connected to a small, circular dug well or jack well, on the river or stream bank.

The construction of a dug well or a dug cum bored well is expensive and time taking. `Down the hole Hammer` rigs have provided an alternative that enables completion of drilling a surface bore well with 150 mm dia upto 100 metres depth, in one day. The cost in India is around US $ 600. The upper portion of the bore well is in soft mantle and weathered rock and has to be supported with steel or PVC casing pipe. Unless this casing pipe has slots near its lower end to allow inflow of water from the phreatic aquifer, the bore well yields all of its supply from the network of fractures and fissures in the hard rock. However, this network is hydraulically connected to the phreatic aquifer and pumpage from the bore well results in elastic compression of the network plus dewatering of the phreatic aquifer.

Experience in Afro-Asian countries indicates that most of the bore wells in fractured rock terrain, meet their supply within first 50 meters depth. In some cases the supply increases by drilling deeper upto 100 meters. Very few bores, less than one percent in India, tap water bearing fissures or fractures below 100 meters depth. However, some of these deep bores do come into the category of `high yielding bores`.

In peninsular India, the basement complex of granite, gneiss, metamorphic and basalt (Deccan trap) cover an area of around 1.15 million sq.kms. Most of the bore wells drilled here fall in the category of low yielding bores, yielding upto 2 cu. m. per hour. In basaltic terrain, there is some correlation between shallow water table and good yield of the bore wells but in granitic terrain such a correlation is not observed. Revitalization of low yielding bores is a topic of great interest to hydrogeologists and farmers. If the low yield is due to the clogging of some fissures during the drilling operation by the rock dust, the yield gradually improves after using the bore for an year or two. Immediately after the rainy season, when the water table is high, the bore well is pumped to create a large drawdown. The clogged fissures get flushed when water rushes into the bore under a greater head difference. Working a rubber rimmed plunger up and down like a piston, below the water table in the bore well, also gives beneficial results in some cases. Blasting up to 2 Kilograms of dynamite charge inside a low yielding bore well is the last resort. The charge may be shrouded in coarse sand. The bore well is filled with water upto the brim and the top of casing pipe is plugged with a cotton ball. Blasting helps in some cases where the fissures, opened up or newly formed, by blasting connect the bore well to more permeable fissures in the vicinity. In some other cases the bore well collapses and is rendered useless. In the remaining cases blasting has no effect on the yield.

Hydro-fracturing of low yielding bore wells is a relatively new technique and requires expensive equipment for injecting large volumes of water under high pressure into the bore, so as to `jack up` the existing low permeability fractures met with in the bore well. Some of these fractures get extended and connect with the network of more permeable fractures, if such a network exists in the vicinity of the low yielding bore well. Hydro-fracturing is commonly used in USA, Australia and South Africa. In South Africa, flow rates of injection water in a successful operation are more than 15 lit/sec at a pressure of 80 bars [2]. It has been observed that hydro-fracturing is more successful at sites which are selected on the basis of lineament mapping and geophysical exploration. At such sites the initial low yield is due to the unfortunate fact that the bore well has missed the main fracture network by a few meters or so, and during hydro-fracturing its connection to the main network is established.

4. Drinking Water Supply

Villages and communities situated away from any surface water source depend on locally available ground water, to meet their drinking water needs. It is economically not possible for them to bring water in pipeline from distant sources. In remote hilly areas in semi-arid hard rock terrain, whatever small supplies of ground water available from dug wells or bore wells, are of vital importance for survival, especially in summer months, even if the yields are as low as 1 cu.m. / DAY. Water table in the fractured and weathered rock overlying the hard rock is high after the rainy season and the villagers get drinking water supply from the spring at the cliff or from the dug well. Towards summer, the water table gradually declines and the spring dries or its yield is reduced to a wet patch, just supporting some vegetation around it. The thickness of the saturated aquifer is negligible at the spring but away from the cliff face the saturated thickness gradually increases upto a meter or so and the dug well is able to yield small quantity of drinking water during summer. Due to small hydraulic gradient and the low permeability, the ground water body does not get completely drained and assumes a `quasi-static stage` towards summer season. In some villages, only the spring water is used as long as the spring runs and the dug wells are brought into use only after the spring dries at the beginning of summer. The cone of depression thus starts developing around the dug well only in summer and not earlier.

In some villages in hard rock terrain, bore wells do not yield perennial water supply due to absence of deeper fissures and fractures. Dug wells of 6 to 8 meters depth also go dry by beginning of summer, due to small thickness of weathered zone, rugged terrain and scanty rainfall. Providing drinking water supply in summer season to such villages by tankers is expensive, especially in hilly terrain. In Maharashtra state in western India, experiments in creating an artificial aquifer by blasting around the existing dug well have been successfully carried out in some villages. In these experiments, about 80 to 120 bore holes of 100 mm dia and 6 to 8 meters depth, were drilled around the dug well upto about 60 meters distance and blasted simultaneously, in order to create a jacket of fractured rock aquifer around the dug well. Such a dug well could then provide a small quantity of drinking water even in summer.

Water from dug wells however, gets easily polluted due to percolations from cattle sheds, septic tanks, manure pits, garbage dumps and fertilizers used on farms. Dug wells located a few hundred metres away and on the up-gradient side from a village have better quality of water. Still, biological contamination and high nitrate values appear in some cases. Villages where drilling rigs have access are therefore, increasingly being supplied with drinking water from bore wells. The commonly used norm in Asian countries is:" One bore well of 150 mm dia and upto 100 metres depth, fitted with a hand pump, for providing water supply to a population of 250 or less." Such a bore well is often the `least cost solution` for providing protected drinking water supply to rural communities, as the cost works out to be just around US $ 0.48 per person per year, even after allowing for interest, depreciation and maintenance at 16% on the initial capital cost of about US $ 750. The quality of water is usually good, if the bore well has a casing pipe upto about 6 metres depth and if the surroundings are kept cleans. In some granitic areas the problem of fluorosis is present but small scale water treatment plants have now been developed.

For remote tribal areas in western India, drilling a bore well and providing a 'bucket pump' has often provided a viable solution for providing drinking water. The cost of bore well of 150 mm diameter and of 60 m depth provided with a bucket pump is about US $400. The bucket pump is manufactured at village level and the villagers could be easily trained in maintaining it. Over 200 bucket pumps are working satisfactorily in the 'tribal area drinking water supply project, sponsored by Dr C. Faillace in the State of Maharashtra in western India[1]

The experience from several Afro-Asian countries, in programmes undertaken by the Government Agencies and by NGOs and Voluntary Organizations, for providing drinking water bore wells in villages, indicates that the following factors are of crucial importance for successful implementation:

1. Selection of a drilling site should be done in presence of village leaders, after careful hydrogeological and if necessary, geophysical resistivity survey.
2. Participation of the local rural community should be encouraged at all stages of the programme, such as providing laborers during the preliminary survey, preparing access road for the drilling rig, providing food for the drilling crew, assisting in the construction of concrete platform around the bore well and looking after proper operation and maintenance of the pump.
3. A facility which is available `totally free` often gets neglected. The villagers should therefore, be required to contribute any amount between 5% and 20% of the cost of bore well and pump. If this is not possible for poor communities, they should at least volunteer their labor.
4. The village council should collect a monthly fee per family for maintenance of the pumps.
5. It is good to involve women in the management and also to train some of the young men and women in the village in hand-pump maintenance.

5. 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: Get information on: The depth, diameter and yield. Also the type of strata met with. The depth 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.

Even within a fractured zone, the intensity of fracturing, interconnections, apertures, infilling matter and recharge from the overlying phreatic aquifer decide the quantity available in a dug well or bore well. Tension fracture zones have usually a higher storage capacity while shear fracture zones could be tight or permeable depending on their stage of development. [7]

6. 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.

Construction of underground impermeable bunds across stream beds is a useful technique in semi-arid regions for retarding the ground water outflow. Construction of a percolation tank by putting an earthen bund with side waste weir across a stream is also very useful because the water stored behind the bund during rainy season gradually percolates during the dry season to recharge the ground water body. A typical percolation tank has a bund of 8 to 10 metres height and a catchment area of about 10 to 50 sq.kms. (Fig. 1 and 2) Ideally, the water stored in the tank should percolate within first 3 to 4 months of the dry season so that the shallow water body is not exposed to excessive evaporation rates in summer months. In western India, thousands of percolation tanks have been constructed in semi- arid region for recharge augmentation after the rainy season is over. In this drought prone area, construction of a percolation tank is also a preferred relief measure by the Government authorities, because it provides employment to about 2,000 people for 3 to 4 months in a drought year. The percolation tank becomes operative from the next year's rainy season.

The storage efficiency of a percolation tank is the ratio of the volume of water stored in the tank at the end of rainy season to the volume of runoff water available from the catchment. The percolation efficiency is the ratio of the volume of water percolated to the volume of water stored. The overall efficiency is the product of the above two efficiencies and is around 40 to 70% for percolation tanks constructed at technically suitable locations [5]. Occurrence of exposed hard rock in the tank bed impedes percolation. So also, silting in the tank bed over the years, reduces both storage and percolation efficiencies. Regular desilting is therefore necessary. A percolation tank and a couple of smaller stream bunds and underground bunds is an ideal combination for recharge augmentation in a sub-basin. In granitic or gneissic areas with fluoride contamination of ground water, storage of rain water by construction of percolation tanks is found to be effecting in diluting the fluoride content and making ground water suitable for human consumption.

Recently, a novel experiment in recharge augmentation was taken up in semi-arid, basaltic terrain in western India, by a voluntary organization. In this experiment, surface water flowing in effluent streams during the early part of dry season, was lifted by the farmers, using their pumpsets and was delivered into several dug wells in each stream basin. About 100,000 dug wells were thus charged with water that would have flown out of the area as surface flow in a few days and its residence time was prolonged to more than a few months. Beneficial effects of this experiment were realized by the farmers during the summer season.

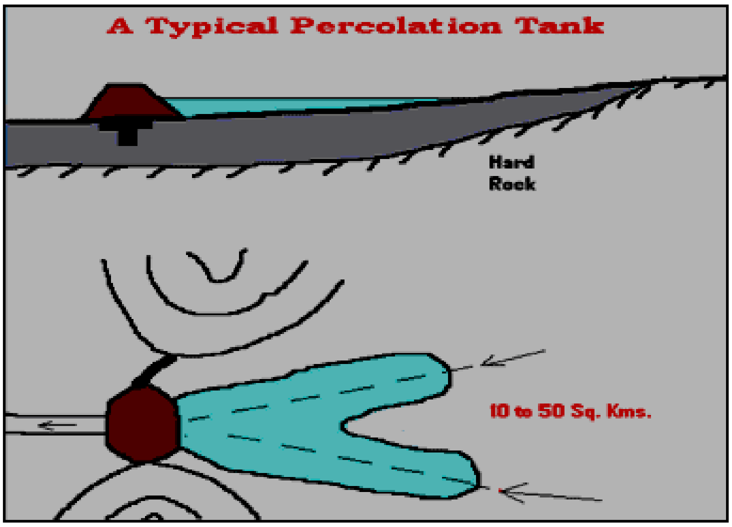

Fig. 1. Cross Section and Plan of a typical percolation tank: Earthen bund is shown in brown colour. The partial cut-off trench lies at the bottom of the bund. Water percolates from under this trench. In the plan, the waste weir is shown in black colour

Fig. 2. Percolation Tank behind an earthen bund stores water in rainy season. The stored water recharges shallow aquifer for 3 to 4 months after the rainy season is over.

7. 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.

However, digging/drilling of new wells cannot be stopped in a sub-basin, so as to protect the yields of the existing, private irrigation wells, because this would amount to capturing of a scarce resource by the privileged few and to permanently denying others an equitable share of the resource. Recharge augmentation efforts should receive priority in over-developed sub-basins, in cooperation with the farmers, their cooperative societies and financing institutions. It is also desirable to incorporate Voluntary Agencies and NGOs in these efforts and through them to advise the farmers to reduce wastage of water. If these efforts are not enough, pumpage control may have to be imposed.

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.

8. 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 [6]. The website www.igcp-grownet of GROWNET project lists the following best practices which are connected to the economics of using the resource:

Exploration & Assessment of Resource (This is necessary to ensure that the wells are dug or drilled at suitable spots where ground water would be available and the percentage of failed wells in minimized.)

Institutional financing for wells / bore-wells for small scale irrigation (Institutional 'soft loans' to farmers should be made available by Banks, so that the farmers are not cheated by private money-lenders.)

Technology for Digging/Drilling of Wells. (Appropriate, low-cost technology should be used to cut down the costs of wells and bores.)

Pumping technology (Pumps should be efficient so as to reduce the electricity charges for pumping water for irrigation.)

Utilization of pumped water for seasonal/perennial irrigation. (The farmer should aim at getting maximum crop per drop, or maximum income per drop of ground water pumped.)

Marketing of agro-products. (Marketing of agro products should preferably be arranged through farmers' cooperative societies. Any 'value addition' at farm level brings better returns to the farmer.)

Recovery of Institutional (Bank) Loans. (The cooperative society for Marketing should pay the loan installment directly to the Bank and then give the remaining amount to the farmer.)

Monitoring of water quality & yields from wells. (Monitoring is necessary so as to check ifthe resource is being over-exploited.)

Watershed management. (This is essential for long-term sustainability of yields from wells)

Artificial Recharge by encouraging participation of beneficiaries (This is also necessary to safeguard the yields from wells)

Implementing pumping regulations. (If actions under 9 and 10 above are not enough to control over-exploitation, the village council has to decide on pumpage control.)

Finding amicable solutions for conflicting interests of stakeholders. (If there is a conflict between stakeholders the village council should try to find an amicable solution.

Role of Women (As women are better managers of scarce resource like ground water, active involvement of Women should be encouraged at all stages from planning to execution of ground water utilization programs.)

Promoting Role of Ground Water in National Economy & National Water Policy. (This is necessary to obtain Government funding on priority basis for restoration degraded watersheds.)

Post Evaluation of Ground Water Development Projects (This is necessary to find out the best practices which were helpful to farmers in getting maximum advantage from resource utilization.)

GROWNET is thus a humble step taken in the direction of meeting the MDGs (Millennium Development Goals) of providing drinking water, achieving food security and mitigating poverty.

9. Conclusions

The policy for 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. Recharge augmentation should be done through percolation tanks 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. Use of aquifers that have marginal quality of groundwater, for irrigation of salt tolerant plants, should be encouraged.
7. Public should be made aware about the true economic value of water. Water, as a resource is a social good, but when supplied in pipeline to families as a service or a facility, water also becomes an economic good.
8. 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.
9. Achievement of pumpage control in overexploited watersheds may only be possible through the recommendations by village councils and through social pressure on a farmer who over-exploits the resource.
10. For sustainable development, it is necessary to build the bridges of understanding and cooperative action between the various stakeholders in water resources.

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