IWMI-Tata Water Policy Research Program

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Over-exploitation and Artificial Recharging of Hard-Rock Aquifers of South India

Issues and Options

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Abstract

This paper, through a case study approach, looks at the reasons for over-exploitation of groundwater, its impact on groundwater quality, cropping pattern, and the ineffectiveness of artificial recharge structures for countering the over-exploitation. The area selected for the case study is the over-exploited zone near Namagiripettai town in Rasipuram taluka of Namakkal district, Tamil Nadu, India. Based on the case study results, it draws broad conclusions and some suggestions for managing the over-exploited aquifers.

Introduction

Ground water use for domestic, industrial and agricultural purposes in India has been growing steadily over the years. The report of the Ground Water Resources Estimation Committee (GWREC 1997) has indicated that in India during the period 1952-1992, the number of dug wells increased from 3.86 million to 10.12 million, while the number of shallow tube wells increased from 3000 to 5.38 million. The total area irrigated by ground water increased from 6.5 million ha. in 1951 to 35.38 million ha. (gross) in 1993. Of the 716 blocks in the country, 250 (3.5%) are "over-exploited" while 179 (2.5%) are "dark" (GWREC 1997).

A substantial portion of the hard rock belts of India, area is experiencing acute conditions of ground water over-exploitation as a result of phenomenal increase in the rates of abstraction of ground water, particularly by the agricultural sector which far cruised the recharge rates. Ground water resources in the hard rock areas face the twin problems of over-exploitation and ground water pollution. Steep lowering of ground water levels and the consequent decrease in well yields has started affecting even small rural communities, creating social tensions between neighboring villages and even among individuals within the same village. The socio-economic dimension of the problem is brought out in a study (Ballukraya 1997) from Kolar district in Karnartaka which showed that out of 84 bore wells drilled during 1980-1992, only 27 bore wells were operational in 1994 indicating the extent of financial loss (capital investment and agricultural income loss) to the rural community.

While insufficient availability of ground water is one side of the problem, the deteriorating quality of ground water is the other side, equally vexing. Pollution of ground water due to external contaminants produced by industrial, urban and agricultural activities is quite well documented (Bhatnagar and Sharma, 2001); over-exploitation of ground water that leads to lowering of ground water levels also leads to increasing content of total dissolved solids (TDS) in ground water.

A major problem encountered in developing ground water resources in hard rock areas is the sharply declining ground water levels, leading to the formation of over-exploited pockets. Bore wells drilled in hard rocks often become unproductive as the weathered/partly weathered rocks as well as the shallower water bearing fracture zones progressively become desaturated. In such areas, bore wells are drilled deeper year after year with the hope of encountering deep fracture zones leading to mining of ground water, since there is no replenishment of the deep fracture zones taking place.

Low-apparent-resistivity anomalies are indicators of having thicker weathered and fractured rock layers in the hard rock areas. These areas are potential targets for constructing successful wells. In over-exploited areas however, there is no correlation between low-apparent resistivity and higher well yields, though some zones with thicker weathered rock layers correspond with low resistivity anomalies. This lack of correlation is due to the fact that most of the ground water in the over-exploited area is obtained from deep fractures embedded in massive rocks. Thus degree and extent of weathering is no guide to availability of ground water in the over-exploited zone. In view of these difficulties of identifying and locating deep fracture zones, sustainably managing the over-exploited aquifers is a challenge requiring very great scientific effort.

Now that over-exploitation exists in many parts of India, it is worthwhile to briefly examine as to what constitutes an over-exploitated area and the indicative hydrogeological parameters characterizing such areas. The report of GWREC (1997) recommends that the level of groundwater development in an area can be assessed by using the ratio of net draft to total utilizable ground water resources. Areas with stage of groundwater development less than 65% are classified as “white”, those with 65% but less than 85% “gray”, more than 85% but less than 100% as “dark” and more than 100% as “over-exploited”. The report further adds that over-exploited areas show significant long-term decline in both pre and post-monsoon ground water levels.

An area may be classified as over exploited if one or more of the following hydrogeological features are encountered:

- When groundwater levels do not recover to their original levels on a long-term basis
- When discharge exceeds recharge by an appreciable volume
- When shallow aquifers progressively become unproductive
- When ground water is pumped from depths[1] greater than that to which adequate recharge currently takes place
- When the natural gradient is reversed and remains so throughout the year.

In order to counter the over-exploitation of hard rock aquifers, the concept of rainwater harvesting and artificial recharge to the ground water system has lately caught the imagination of technocrats dealing with water resources as well as lay public. It is well known that artificial recharging of aquifers has in many cases resulted in a remarkable recovery of ground water levels locally in the vicinity of artificial recharging structures, at least in the first few years of their construction. The question to be examined, however, is the effect their construction may have made on the ground water environment in areas further downstream, that is the area to which

[1] Ballukraya (1997) analyzed the increase in yield of bore wells at different depth after recharge period in Kolar district, Karnataka and shown that recharge in hard rock aquifers was largely restricted to depth of about 60m below ground level though most of the presently tapped water bearing zones were at depths greater than 60m.

the stream run off would have flown and recharged the aquifers had the recharge structures not been constructed.

The most common artificial recharge structures are percolation ponds, check dams, sub-surface dykes, spreading basins and injection wells. In the hard rock areas of South India, hundreds of over-exploited pockets exist. During the past two years, a large number of artificial recharge structures in South India are being constructed in such areas years.

A look at the South Indian terrain shows that in areas underlain by hard rocks, a very large number of tanks (small reservoirs) have been constructed by impounding streams at a number of locations. These cascading tanks, apart from storing runoff, also act as source of ground water recharge. It is also noticed that in most of the over-exploited areas, these tanks remain totally or partially dry for a substantial part of the year due to lack of adequate run off. This is caused by increased infiltration of rainwater due to declining groundwater levels. Thus, in a normal or below normal rainfall year, many of the over-exploited watersheds do not generate any significant surface runoff. Under these conditions, where already adequate number of tank structures exist for storing run off water, the potential benefits from constructing more and more artificial recharge structures need to be examined more carefully before embarking on large scale construction of these recharge structures.

This paper through a case study approach looks at the reason for over-exploitation, its impact on ground water quality, cropping pattern, and the in-effectiveness of artificial recharge structures built for countering the over-exploitation through construction of. The area selected for the case study is the over-exploited zone near Namagiripettai town in Rasipuram taluk of Namakkal district, Tamil Nadu. Based on the case study results, it draws broad conclusions and some suggestions for managing the over-exploited aquifers.

The Study Area

The study area, Rasipuram, approximately 250 km^2 in extent (Figure 1) is located on the foot hill slopes of the Kolli hills to the east and Bodamalai hills to the north. The area has drainage characteristics of near-desert conditions, in that most of the mountain streams terminate as soon as they reach the plains. Only two major streams of appreciable length passes through the area. A large number of small-sized reservoirs (tanks) are found in the area. However, almost all these reservoirs remain dry for most part of the year, with no area under agriculture depending on them. In fact, all these tanks are silted up and covered with plants belonging to the species prosapsis juliflora.

The study area is underlain predominantly by charnockites with occasional pockets of granitic gneisses, as well as a few bands of ferruginous quartzites (BIF) and dolerite dykes. On an average, the thickness of weathered rock is 10-15m. Below the weathered rocks, fractured rock is encountered. The area is structurally disturbed, the rocks having undergone fracturing, jointing and shearing. Results of bore well drilling show that water-bearing joints occur up to a depth of 300m below ground level. Thickness of these jointed zones, wherein the rock is generally particularly weathered, is about 20-30cm on an average as seen from drilling results.

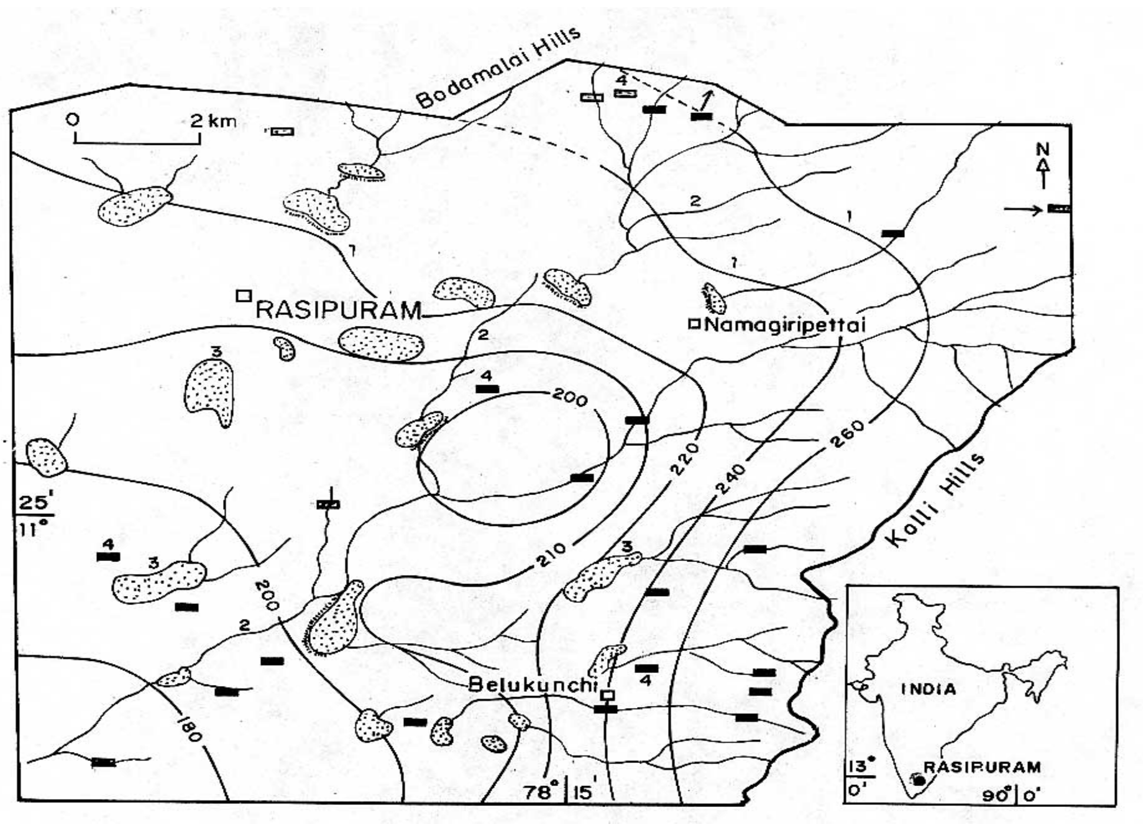

Figure 1 Map of the study area showing hydrological details. Groundwater level in m, above mean sea level ;2 Drainage/stream; 3. Tanks ;4 Newly constructed artificial recharge structures

Rasipuram and the surrounding areas have an average rainfall of 700mm. The area practices intensive agriculture. Ground water is the only source of water for domestic, agriculture and industrial needs. The area has a high density of dug wells and bore wells. The density of dug wells averages at 37 per sq. km. In some places like Oduvankurichi, the density of agricultural bore wells alone is over 70- per sq. km.

A study of historical hydrogeological data indicates the level of ground water development in this region. Figure 2 shows the average depth of agricultural bore wells drilled during the period 1982-1998. The average yield of bore wells, both at the time of drilling and in 1997-98 are also shown in the figure. The depth of bore wells has increased three-fold in the last 30 years from an average of 60m in 1980 to 175m in 1997-98. The maximum depth of bore wells in the area is about 350m and in certain pockets, the least depth drilled for agricultural borewells in 1997-98 is 180m. The depth at which the first water-producing zone encountered in such areas is anywhere between 100 to 160m. Dug wells of less than 35m depth are all unproductive in such zones. Of the 1213 borewells inventoried in 1997-98, the depth of borewells varies from 50 to 350m with an average of about 116m. Thirty percent of inventoried wells have depths less than 90m, 63% have depths 90 to 180cm and 7% are over 180m deep.

It is significant that all through the period of 18 years, despite a steady increase in the average depths drilled in each year, the average yield at the time of drilling has remained approximately at around 70 lpm. In fact, a slight decrease is noticed in the average yield over the years. The average yield in 1997-98 is, however, about one third of the drilling yield, at approximately 23 lpm.

Almost all the dug wells in the central part of the study area, a majority of which are 30m or more in depth, are not productive and used at present as storage tanks to collect the discharge of bore wells. This is because the yield from the bore wells is generally low, 30-40 lpm on an average and this is not adequate for it to be directly used for watering fields. The bore wells are pumped for long periods and the discharge stored in these dug wells for it to be used for irrigation at a convenient time.

From the contours plotted in Figure 3 it is seen that a clear-cut ground water trough forms at the central part of the area, though the general hydraulic gradient is to the south-west, which is the same as the direction of ground slope. In the central part of the area, the hydraulic gradient has been reversed due to steep decline in ground water level there.

Figure 4 is a profile from west to east, showing both the ground and ground water elevations along this line. The elevations of ground water levels during post-recharge season and pre-recharge season (highest, lowest) are shown. These indicate the magnitude of net recharge that takes place in the area. In the eastern parts (higher ground elevation), the ground water level reverses by as much as 16m, in a hydrological year, while it is only 4m in the trough area. Thus, it is very clear that in the area where trough is located, ground water is being pumped far in excess of annual recharge indicating a case of ground water mining.

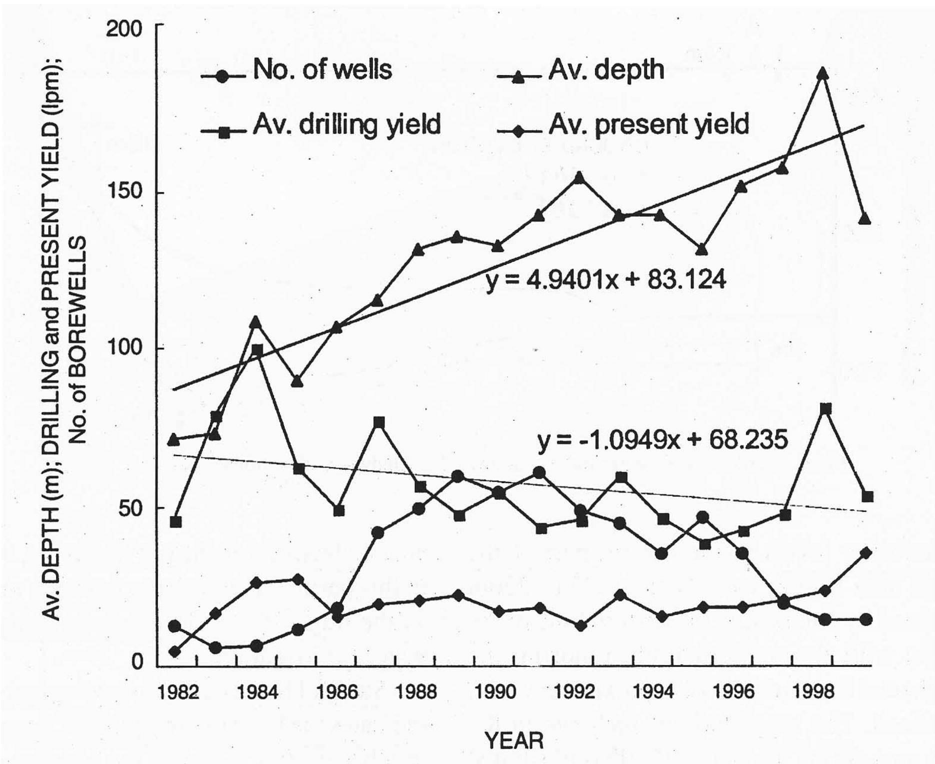

Figure 2 Histogram showing year wise changes in average depth and yields of agricultural borewells

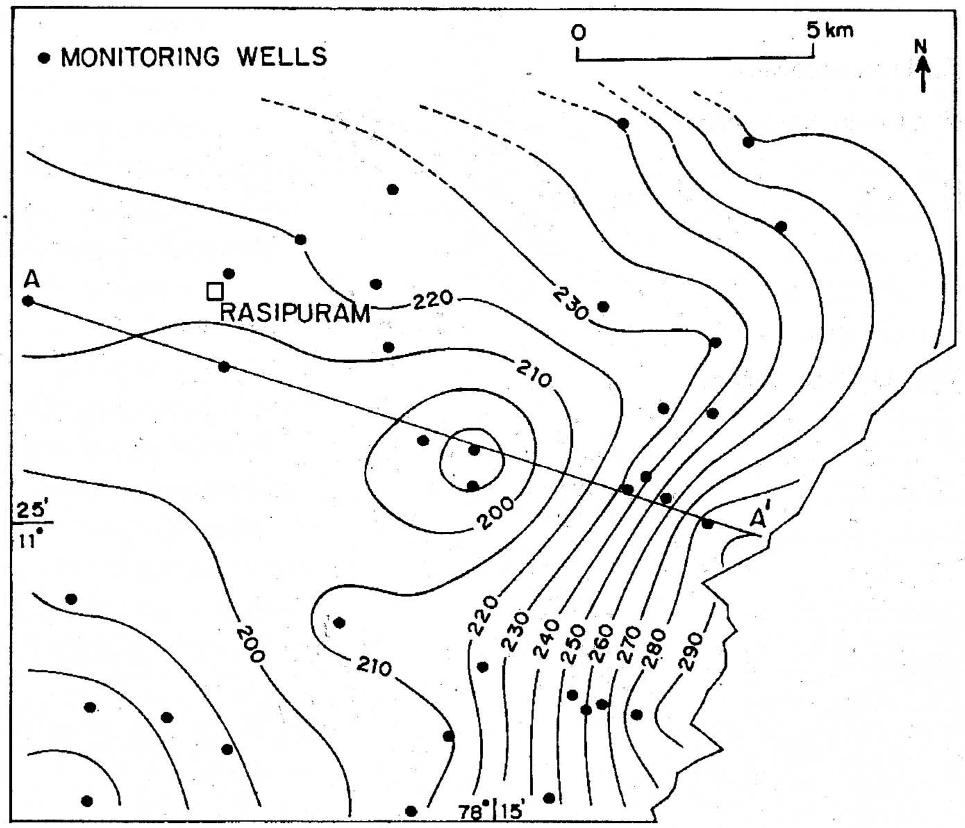

Figure 3. Groundwater level (in metres, above mean sea level, for August 1998) map of the area.

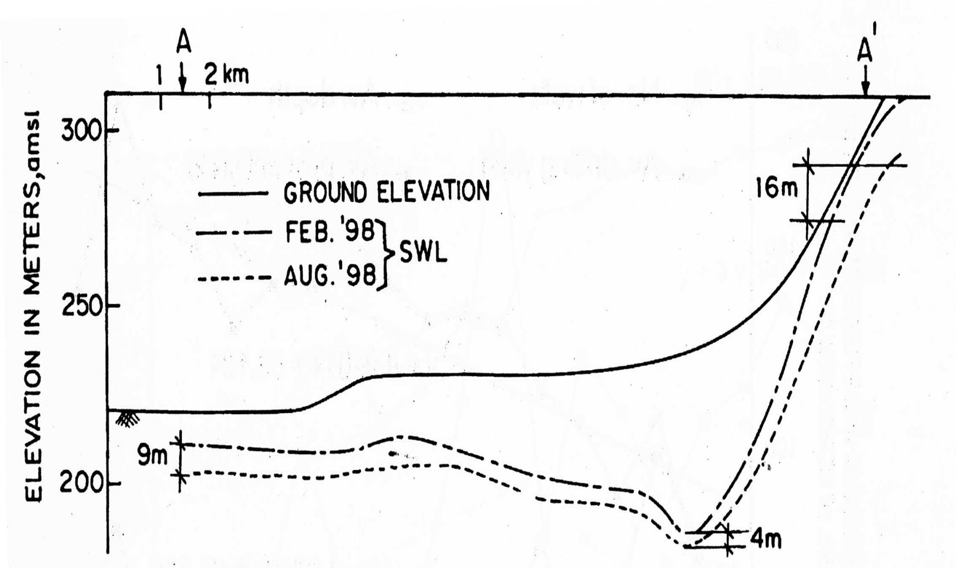

Figure 4 Profiles showing ground elevation and groundwater elevations across AA[1]

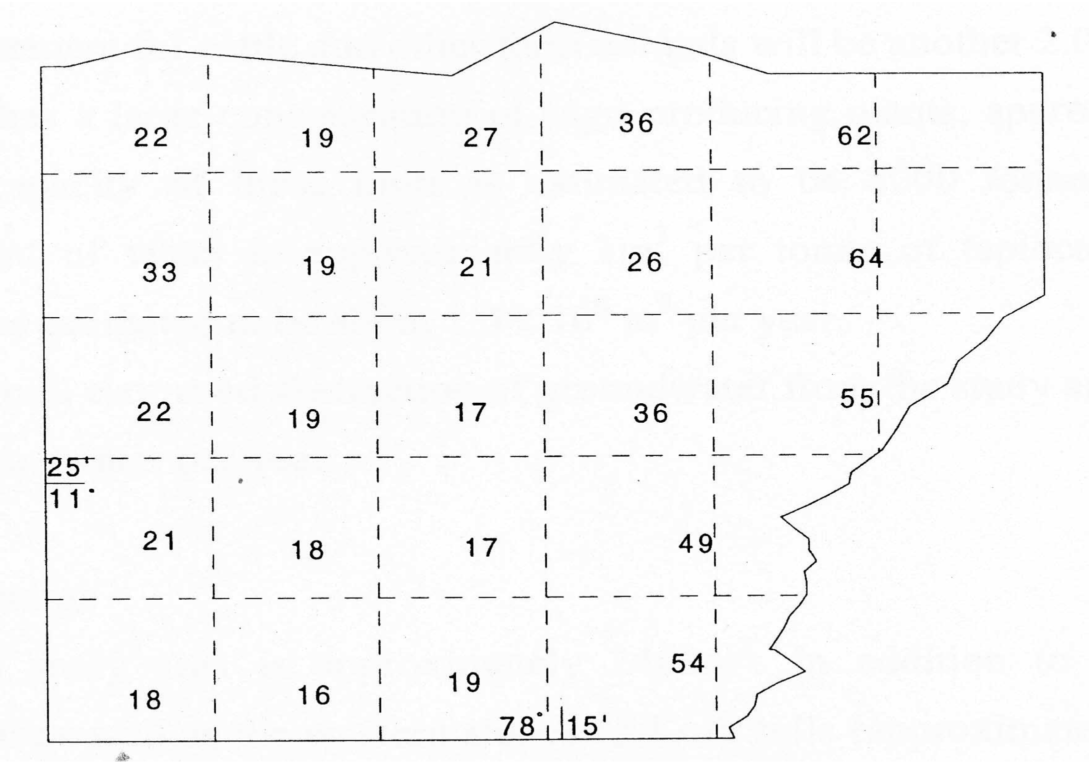

Figure 5. Percentage of area under Groundwater Irrigation each block is 10 sq.km (except the blocks in the northern and eastern boundaries)

Pollution due to Over-Exploitation

Pollution of ground water due to variety of external factors, most of which are related to man's activities are well known while that due to over-exploitation of ground water and consequent increase in TDS is less understood. It is a well-known fact that the recharging water during its downward movement through the zone of aeration dissolves mineral matter thus enriching itself in total dissolved solids. This dissolution continues even in the zone of saturation due to rock-water interaction during the residence time of ground water in the host rock. The enrichment of ground water in TDS is faster in the zone of aeration as compared to in the zone of saturation.

When the ground water table declines below the stream bed, there will obviously be no base flow and thus all the salts carried in solution by the percolating waters will reach the ground water regime, resulting in brackish ground water. When ground water is used for irrigation in such areas, its recycling will rapidly increase the salinity of ground water by repeated circulation-from surface to deep levels through the intermediate soil water zone and back to surface –in addition to evapotranspiration. The ground water chemistry in areas with granite rock compositions will be dominated by acid hydrolysis reactions of the primary silicate minerals (mainly feldspars) releasing additional cations into the system. Increase in HCO_3 along with silica also is a common occurrence with depth.

Increasing TDS has been a problem in the study area for over a decade now. Farmers in that area report that in several villages, cultivation of paddy has been discontinued due to high levels of hardness of groundwater, which retards the growth of paddy crop. Encrustation of discharge pipes in bore wells is very common necessitating replacement of the pipe once every 5 years. The spatial distribution of total hardness in ground water in the area indicates that hardness is highest in the region where the groundwater levels are low, particularly in the area surrounding the ground water trough zone (Ballukraya, 2000). This area is totally devoid of base flows even after heavy rainy periods and groundwater is recirculated over and over again, at least during the last two to three decades.

Crop Pattern

Lowering of groundwater levels and consequent drying up of bore wells has had a profound impact on cropping pattern and land use in the area. Much of the irrigated cropped area has now been converted to rainfed area. Even where irrigation is attempted, the trend is towards crops that require less water. Thus the cereals and sugarcane cultivation has given way for mainly tapioca. Large-scale cultivation of tapioca crop has inevitably resulted in setting up of several units for processing the tuber into starch or edible sago. These units not only consume large quantities of ground water but also generate effluents rich in organic chemicals. Such effluents contaminate the ground water environment since they allowed to infiltrate into the ground. In fact several wells in the vicinity of these units have already been polluted, leading to non-availability of even potable water to the local population. The main chemical pollutants from these units are sulphuric acid and bleaching powder used in processing tapioca tuber to starch. Thus over-exploitation of ground water results in a vicious circle of lowered water levels -> reduction in irrigated agricultural area-> industrialization->groundwater contamination-> further reduction in ground water availability, which has far-reaching repercussion on the local population.

Estimation of Ground water Balance

The general method adopted in this case is the following: The study area is divided into $10km^2$ blocks- with bordering areas slightly more or less in extent in the eastern and northern border blocks (Figure 5). The recharge and discharge estimation was carried out for each block separately. The discharge of ground water is dependent on the area under ground water irrigation, duration of crops and average water requirement of the crops. Irrigated area as percent of block area is computed as area under crop multiplied by duration of the crop divided by 12. For example, for sugarcane, irrigated area = crop duration/12 = 12/12 = 1. For paddy crop, it is 4/12 = 0.33. If 2 paddy crops are raised in a year, then the value will be 0.33x2=0.66. By this method of computation a total area of 70 km^2 out of 240 km^2 is under ground water irrigation on an annual basis. Considering the crop mix, the irrigation water requirement per day is taken as 6mm or 60 m^3 per ha per day. Taking on irrigation period of 250 irrigation days in an year, the yearly requirement of ground water works out to 15,000 m^3 per ha per year. Thus, the total annual ground water abstraction for irrigation is 70x1000x15,000= $105x10^6m^3$ The approximate population of the area is estimated to be around 300,000. At an average rate of 100 litres of water per person per day, the annual domestic requirement will be

$$300,000x365x\frac{100}{1000}=60,000x73 = 11x10^6m^3$$

The requirement for cattle and other farm animals will be another $2x10^6m^3$ per year.

The area has a large concentration of sago producing plants and the total production of these units is estimated to be 8000 tones per year and the average requirement of water is approximately 1 m^3 per kg of tapioca. The industrial requirement therefore is estimated to be about $1x10^6$ m^3 per year. Thus, the total estimated abstraction of ground water from the study area is of the order of $119x10^6$ m^3 of ground water per year.

The total recharge area is approximately 300km^2, which includes the study area plus the additional area of about 60 km^2 bordering the southern slopes of Bodamalai and the western slopes of Kolli hills forming the recharge zone. The main annual rainfall (10 year average for the four stations) is 632mm. There is no run off from the area and the actual evapotranspiration is taken as 50% of the rainfall considering the climate and rainfall intensity. The total annual ground water recharge due to precipitation therefore is approximately 0.316x300x 10^6= $95x10^6$ m^3 per year. Adding a return recharge of 10 percent from ground water use ($119x10^6x0.1=11.9x10^6$ m^3), the net ground water recharge is $107x10^6$ m^3 per year. Thus there is an excess abstraction of $12x10^6$ m^3 per year or roughly 11% of net recharge. However, the rate of abstraction and the recharge is not uniform in the area. The recharge is much higher in the foothill slopes since the precipitation on the western slopes of the hills flow towards these areas recharging the groundwater system there. The central parts do not get any additional recharge, as there is no runoff reaching it from hills. For example if we were to take one of the blocks such as Oduvankurichi with 36% (3.6 km^2) under irrigation, the total ground water abstraction works out to be $3.6x100x15,000=5.4x10^6$ m^3. Along with domestic and industrial needs, the total abstraction from this block is approximately $6x10^6$ m^3. The total recharge works out to only $4.24x10^6$ m^3 of water, leaving a deficit of $1.76x10^6$ m^3 per year, which is approximately an utilization rate of 44% in excess of total recharge. Therefore, ground water over extraction varies with the scale of the area considered for computation, larger the area lower the over extraction and vice-versa.

Cost-benefit analysis:

A study of ground water usage by the farming community reveals that one of the prime reasons for over-exploitation is the supply of free electricity to the agricultural sector. It is very common to see farmers pumping very small quantities of water, all through the day or as long as the power is available. A majority of the wells pump less than 50 lpm in the heavily over-drafted area that can barely support crop in 0.4 ha (1 acre) plot of land. In terms of economical use of water, this is a highly unprofitable effort as can be seen from the following analysis:

Cost:

Energy consumed per year of 250 days by a 10HP motor pump set (air-lift pump) for a 16hr per day pumping period = 7.5 kw/hrx 16hrx250 =30,000 units.

Cost of 30,000 units of power at Rs.2 per unit=Rs.60,000/-

Benefit:

Net realization from 0.4 hectare of sugarcane crop 50 tones at Rs.600 per tone = Rs.30,000/-

Even taking a highly optimistic rate of return as shown above, every borewell results in a loss of Rs.30,000 to the state.

For breaking even, a reasonable estimate is a yield of at least 100 lpm that could irrigate about 1 ha of land. Any pumping less than 100 lpm results in a net loss to the state since it spends more money on supply of energy than the net value of crop produced. Of course, to the family concerned, it is a means of survival as long as the power is free or highly subsidized. But from a macro economic point of view, it is unviable proposition. This is in addition to the stress on the ground water environment caused by over-exploitation of ground water.

The answer to the problem lies in charging for electricity used by the farmers. If the individual is compelled to pay the actual electrical charges then he will realize that it is not profitable to engage in ground water irrigated agriculture under the prevailing circumstances (low well yield). If such pumping is discouraged, there will be significant reduction in the rate of ground water abstraction, which will in turn gradually restore the ground water levels. It is suggested that in the over exploited zones, power supply is stopped to all uneconomical wells in an identified watershed for a period of say 5 years and the well-owners who are prevented from pumping could be suitably compensated for the loss of income by irrigation. Such a move will lead to significant saving in ground water abstraction and rise in ground water levels over a period of 5 to 10 years.

Artificial Recharging

In the study area, the mountain streams do not bring any surface flows into the plains even during normal rains. This can be attributed mainly to two factors: 1. construction of large number of check dams in the hills, which impound flood waters and base flow for forest nurseries, town water supply and 2. Lowered ground water levels in the region contiguous to the foothills leading to heavy infiltration of whatever runoff issues from the foothills during the rainy season. Discussion with the farmers indicates that tanks in this area have not received any significant flows for the past 15-20 years and many of them with whom we have discussed in fact relate it to the construction of check dams in the upper reaches. (Figure 1)

Absence of any runoff and consequent lack of ground water recharge has caused a decline in ground water levels by as much as 50m. in the central part of the study area. Construction of check dams have obstructed natural surface flow as well as groundwater recharge in the riverine area. Of course, wells close to the recharge structures have benefited from increased recharge but unfortunately at the expense of zones further downstream.

Considering that there is no significant outflow from the study area and the fact that existing tanks do not get filled up, the need for constructing these artificial recharge structures was really non-existent. Though these structures may marginally increase the well yields in their vicinity, the ethics of constructing them is questionable as any benefit derived is at the expense of water wells further downstream from such structures.

Construction of new check dams across streams which already are unable to fill the existing tanks along them may even amount to disregarding the riparian rights downstream of water users. The same arguments hold good in the case of subsurface dams/dykes as well.

Artificial recharging of over-exploited aquifers calls for a detailed analysis of the hydrology and hydrogeology of the watershed, the present water use and the impact of introducing new water harvesting and recharge structures on the existing water use and ground water level conditions. In watersheds that are closed, extra caution is to be exercised in introducing new water harvesting structures that will disturb the existing equilibrium of water use between surface and groundwater.

Findings of the Study

1. The area studied is one of the very highly over-exploited with over 125% rate of ground water utilization through deep hard rock zone and high density of dug and bore wells per sq. km.

2. The depth of borewells is increasing at a fast rate (already exceeding 200m depth in many situations) as a consequence of drying up of water-bearing horizons at shallower depths. Not many can afford to drill such deep wells and install costly pumping equipments. The economics are prohibitive particularly since it is estimated that every additional metre of pumping head involves an additional 0.4kwh of power on an average.

3. The study indicates that water-bearing horizons at depth more than 100 metres may not be getting adequate recharge at present and therefore ground water abstraction from these deep fractures are not sustainable over long periods. Pumping from a depth greater than 100 metres in hard rock aquifers constitutes a case of ground water mining in the over-exploited pockets.

4. In overexploited hard rock aquifers, increasing total hardness and salt accumulation in ground water will be a serious problem.

5. In over-exploited hard rock terrains, no perceptible correlation exists between resistivity parameters and the geohydrological characteristics of the aquifer. The poor correlation between the various parameters is basically due to the fact that the availability of groundwater and its magnitude depends on the chance encounter of water-bearing fractures in the unweathered bedrock and these do not, apparently have any linear expression on the surface.

6. A perceptible trend is observed in the cropping pattern from cereals to cash crops such as tapioca in the study area. Tapioca cultivation has encouraged setting up of processing industries, which cause not only further depletion of groundwater levels but also contamination of ground water.

7. The discussion in this paper clearly brings out the fact that availability of excess surface flows (over and above the present use) must be a pre-condition for putting up any future artificial recharge structure. This availability on a watershed basis must be estimated by taking into account the capacity of existing tanks in the watershed after their desilting and rehabilitation. Priority must be for desilting rather than construction of new check dams/percolation ponds/sub-surface dams.

8. Artificial recharge in closed basin/watersheds at best is a short-term solution, and like all such remedies which alter/modify natural systems, may have undesirable long-range consequences. This must be carefully analyzed through modeling before undertaking any recharge project.

9. The real solution to the problem lies in judicial use of available groundwater resources and ensuring that the rate of abstraction does not exceed the long-term annual rate of ground water recharge. For this to be implemented, groundwater legislation and water use rights must be prescribed and enforced through stakeholders' participation.

Issues and Options:

Issues

In over-exploited aquifers such as the one studied herein the issues are clear: the rate of groundwater extraction exceeds the long-term annual rate of groundwater recharge. This is mainly due to availability of free electricity coupled with no ground water institutions and regulatory measures to manage the ground water aquifers. The stakeholders' involvement in managing the aquifer is limited. Over-exploitation of ground water results in vicious circle of lowered water levels -> reduction in irrigated agricultural area->industrialization->groundwater contamination->further reduction in groundwater availability, which has far reaching repercussion on the local population.

Options

The following options if implemented properly, have the potential to arrest the falling water table and would allow a sustainable ground water use:

1. Maintain tanks by desilting and use as artificial recharge structures. The revival of the institution of community management of tanks is crucial. The other option would be to make it mandatory for farmers under the tank command to maintain and desilt tanks. Strengthen the budgetary allocation of Public Works Department (PWD) for tank maintenance. Incentives could be provided to farmers who desilt tanks, build conservation structures within their field and use water conservation techniques in cultivation. The density of wells below the tank could be tied to the quality of tank maintenance.

2. Impose conservation requirement such as a) drip and sprinkler irrigation systems b) raising of low water consuming crops c) reducing non-beneficial uses of water by fallow land, by shrubs and weeds and d) improved discharge efficiency of abstraction mechanisms.

3. Regulate well drilling agencies: Permits should be obtained by the well drilling agency, rather than farmers, before drilling tubewells. This would

make management for the groundwater authority easier, as the drilling agencies will be few in numbers.

4 Regulate the depth of drilling and spacing between wells. This will prevent mining of static water table. Tube well greater than 200m depth should not be allowed to drill.

5. Enforce limit on pumping rate. Any well pumping less than 30lpm must be prohibited from pumping by suitable compensation. Provision of free electricity should be dispensed with. Price electricity on pro-rata basis on a graded scale. Electric meters and water meters should be installed to measure ground water use on farms. Price discounts could be offered for conservation efforts and for those who consume the right quantities prescribed for the crop and penalties could be charged for those farmers who over irrigate the crops.

6. Time electricity supply for improved water management. Supply of electricity during night has resulted in excessive use of groundwater because of the difficulty in managing the irrigation. Supply during the daylight hours would help conserve water and also enable the farmers to monitor the water use.

7. Provide incentive for rain water harvesting for drinking and industrial uses. Encourage reclamation, recycling, and reuse of wastewater through tax incentives.

8. Establish groundwater management committee at village, block and watershed levels. This would help to enforce correlative water rights to balance the recharge and discharge and help prevent long term overdraft of groundwater. Rates at which groundwater is withdrawn and to replenish the aquifer need to be determined to overcome the already existing overdraft condition. The selected rate of withdrawal could be shared among farmers based upon individual quotas. The quotas could be set based on the need of individual farm family. This would also lead to groundwater market among farmers.

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