Ind. Jn. of Agri. Econ.
Vol. 52, No. 4, Oct.-Dec. 1997

Externalities in Groundwater Irrigation in Hard Rock Areas

M.G. Chandrakanth and V. Arun*

INTRODUCTION

The total volume of water on the earth is 1400 million cubic kilometres and this can cover the earth 3000 metres deep. But, 97.3 per cent of this water is salt water and only 2.7 per cent is fresh water which is useful for drinking and irrigation. Of this fresh water, 75.2 per cent lies frozen in polar regions, 2.2 per cent is available as surface water in lakes, rivers, atmosphere and moisture, and 22.6 per cent is available as groundwater (Government of India, 1996, p. 1). The groundwater resource for irrigation is the nature's benediction to agriculture in the hard rock areas (HRA) of southern India where the hydro-geomorphological features are not as favourable as in alluvial plains of the Gangetic basin for recharge. HRAs in India are at least 60 per cent of the total geographical area. Many tend to think of groundwater as underground lakes or streams or as fossil water, which are extremely rare. Groundwater is simply water filling spaces between rock grains or in cracks and crevices in rocks. The rock layer that yields sufficient groundwater is called an aquifer. Aquifer may be a few feet or hundreds of feet thick; located just beneath the earth surface or hundreds of feet down; underlying a few acres or thousands of square miles. Groundwater does not occur downward all the way to the core of the earth. At some depth beneath the water bearing rocks, the rocks are water tight.[1] Obviously the volume of water held depends upon the ratio of open space to total volume (porosity).

Characteristics of Aquifer

The occurrence of groundwater in the unconfined aquifers in the HRAs is highly sensitive to interactive effects of wells and renders groundwater as a fugitive resource. Such aquifers yield water by draining of materials near the well. In the HRAs about 90 per cent of the aquifers are unconfined. The nature of groundwater rights is intricate and the rights are dynamic and are functions of the demand and supply side forces determining the availability of groundwater (Figure 1).

---

* Professor and Head, Department of Agricultural Economics, University of Agricultural Sciences, Bangalore-560 065 and Research Associate, National Centre for Management Development in Agriculture and Rural Development Banking, Bangalore-560 070, respectively.

The authors are thankful to all the farmer respondents who have provided field data for this study; to John Ambler and Ujwal Pradhan of the Ford Foundation, New Delhi, for the facilities provided for this study, D.S. Gundu Rao, Department of Mathematics, University of Agricultural Sciences, Manjunath, Statistician, Department of Poultry Science, University of Agricultural Sciences, and H. Chandrashekhar, PPMC, University of Agricultural Sciences, Bangalore for their comments and suggestions. The authors are thankful to the anonymous referee of the Journal for critical comments and suggestions regarding nature of groundwater rights and externalities. Thanks are due to Shri K.K. Ananda, Systems Analyst of the Department for helping in drawing Figure 1 in the PC.

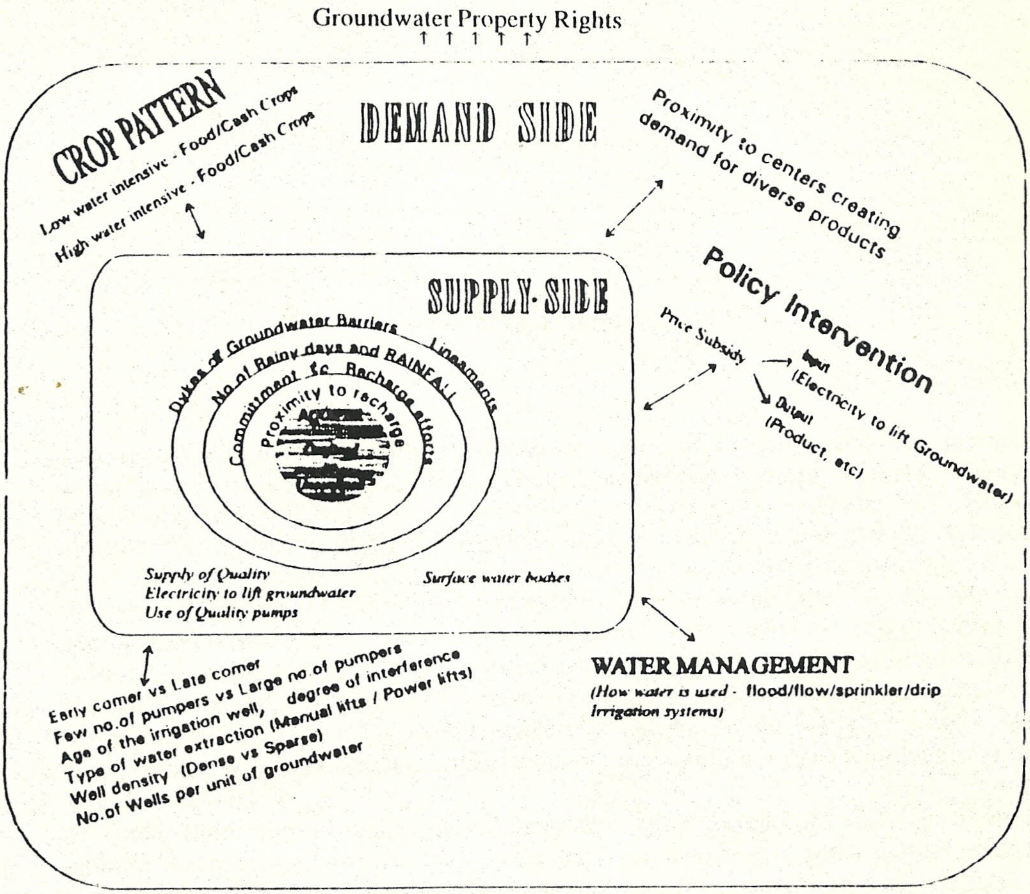

Figure 1. Dynamics of Property Rights in Groundwater in Hard Rock Areas of India - A Heuristic Scenario

Dynamic Nature of Rights

The property rights to groundwater are dynamic and change with supply and demand side factors which jointly determine the property rights. A farmer who is an early comer in groundwater irrigation growing low water intensive crops lifting water from dug well with manual lifts, almost feeling that he is enjoying (permanent) private property rights to groundwater, will suddenly be shattered once there emerge a set of neighbouring farmers who tap groundwater from deeper layers from borewell causing cumulative well interference effects resulting in permanent failure of the dug well.

Property Rights to Groundwater

Groundwater is an indispensable resource for irrigation in many pockets of HRAs especially where there are no flows of perennial rivers. In India, the rights in groundwater belong to the landowner as groundwater is attached to the land property. There is no limitation on the volume of groundwater extraction by a landowner. Since, land ownership is a pre-requisite to ownership of groundwater, it is difficult to assign 'open access' nature to groundwater resource (Singh, 1992). Though landowners own groundwater *de jure*, this right is limited by the huge investment necessary to tap the groundwater by construction-/drilling of irrigation well(s) and high well failure probability, which makes a selected few among them to have access to groundwater. Unless groundwater is tapped in a well and is available, there is no accessibility, since there is no guarantee that any landowner who attempts to construct/drill a well is assured of groundwater, even for a short period. Initial failure and falling life of irrigation wells is a common feature in HRAs. In the eastern dry zone of Karnataka, the (negative binomial) probability of well failure is estimated to be 40 per cent (Nagaraj *et al.*, 1994), which means that a farmer has to drill at least two wells, one of which may be successful. It is crucial to realise that 'wells can exist without groundwater' and not vice versa !

Under these circumstances the groundwater rights are obscure since the farmers are tapping the resource with myopic behaviour, not recognising the fact that each one's extraction is a function of the neighbouring well's extraction at a time and over time. This over time is leading to cumulative interference of wells and reduction in life of the wells and in the gross area irrigated by wells. Ciriacy-Wantrup (1969) indicates that groundwater is a 'fugitive resource' since 'definite property rights belong only to those who are in possession - that is who gets there fastest with the mostest'.

Externality

In groundwater, the inter-temporal externality is the externality imposed by each well owning farmer on another well owning farmer over time at a given space. "Due to inter-temporal externality, the drilling costs increase as the water table falls" (Dasgupta, 1982). The externality affects both the poor and rich people, both spatially and temporally. These factors are discussed to show how the bore well farmers get better access to groundwater when compared with the traditional dugwell farmers.[2] In this study, a modest attempt is made to value the negative externality in borewell irrigation and to study the farmers' response to well interference externality in Bangalore and Kolar districts of Karnataka, where the groundwater irrigation is intense (Arun, 1994).

METHODOLOGY

A snow ball sample of borewell farmers whose well(s) are interfered forms the sample units. The first farmer whose well is interfered was located with the help of a local water diviner. Later the first farmer was asked to give the name and location of the next farmer who was similarly placed, and this procedure was followed till a sample of 40 farmers was obtained. In order to obtain this sample of 40 farmers, 20 villages located in four taluks of Bangalore rural and Kolar districts had to be contacted. Both the snow ball sampling and locating the farmers whose well(s) were interfered were onerous tasks, since the farmers would not confess openly about interference of their well(s) for social reasons. The field data were collected by primary survey through personal interviews for pre-well interference and post-well interference periods and pertained to the year 1993-94. The pre-well and post-well interference years differed from farmer to farmer.

EMPIRICAL FRAMEWORK

The response to mitigate the externality is measured in two steps. In the first step, conditional probability of drilling additional well(s) is estimated and in the second step, the farmer's marginal willingness to pay for additional well(s) (MWTPAW) is estimated. The conditional probability of drilling additional well(s) as a response to negative externality is measured by estimating a logit model $L^* = Z = A + \Sigma \beta_i X_i$, where $L^* = L_n [P_i / (1 - P_i)]$, P_i = probability that the farmer drills additional well(s), X_i refers to independent variables as explained in Table 1.

Next, the willingness to pay for additional well(s) (WTPAW) is estimated using WTPAW $= C + \Sigma \alpha_i \, d X_i$ by Tobit maximum likelihood method. X_i refers to independent variables as explained in Table 1. If a farmer did invest in an additional well, it was taken as willingness to pay and for a farmer who did not, the willingness to pay was taken as zero.[3] The WTPAW is the closest proxy for the cost of negative externality.

Construction of Variables and Rationale

1. *Size of Land Holding* (SIZE)

Land value forms around 60 per cent of the value of all physical assets of farmers in India. The farmers' potential to invest in additional well(s) depends on the size of their holding. The sample farms are located around 50 kilometres of the densely populated mega city of Bangalore; there is a perennial demand for high value commercial crops like vegetables, flowers and fruits which makes land, a crucial decision-making variable influencing the probability and willingness to pay for drilling additional well(s).

2. *Ratio Variables*

The area irrigated and the profitability in the pre- and post-interference situations are hypothesised to have a bearing on the negative externality. Farmers are postulated to follow a mini-max strategy while reaping returns from groundwater irrigation. Expectation of profits depends directly on the extent of groundwater availability for irrigation. Farmers were aware of the general decline in the availability of groundwater. Hence when their first well (or first set of wells) failed, some of them invested in additional well(s) in order to at least remain on the original isoprofit curve. This can conveniently be considered as a mini-max strategy as they wanted to minimise their maximum loss. Their prudent allocation of irrigated land to cereals, mulberry and vegetables shows their intention to diversify for enhancing the risk bearing ability and also to endure with groundwater decline.

The average size of holding was 6.83 acres of which the well irrigated area was 4.48 acres. In the post-interference period, the gross irrigated area under cereal and vegetable crops fell by 41 per cent and 56 per cent respectively, while the area under mulberry increased by 21 per cent compared with the pre-interference period levels. The increase in the area under mulberry accounted for 37 per cent of the fall in area under cereal and vegetable crops. The overall annual profits fell in the post-interference period by 31 per cent (Rs. 8,736), and that for cereals, vegetables and mulberry fell by 60 per cent, 18 per cent and 32 per cent respectively.

The area irrigated and profitability from well irrigation in the post-interference period are related to the pre-interference period using the ratio of area irrigated (profit realised) in the post-interference period to that in the pre-interference period.[4] As indicated above, cereals, vegetables and mulberry are the major crop combinations followed by farmers. The aftermath of interference is postulated to manifest through the following effects: (i) reduction in the area under crop(s) and/or (ii) intra-farm area adjustments among crops such that the farmer remains at least on the same isoprofit curve as he/she was in the pre-interference period. The ratio variables and the rationale are provided in Table 1.

Each of the ratios relates a variable in the post-interference period to the related variable in the pre-interference period. Each ratio subsumes the effects of intra-farm adjustments and/or changes between pre- and post-interference effects in a dynamic response setting. The first three ratios indicate the farmer's coping mechanism towards adjustment of irrigated area. The second two ratios indicate the farmer's coping mechanism towards profit, as a result of the adjustment in the area irrigated. For instance, if the gross area irrigated devoted to vegetables (or profit from vegetables) in the post-interference period forms a low proportion of gross area irrigated under all crops (or profit from all crops) in the pre-interference period, then the farmer ventures to invest in additional well(s), since he/she has suffered due to well interference which forced him/her to reduce the area under vegetables (lose substantial profits from vegetables). If the area irrigated in vegetables (or profit from vegetables) due to well interference forms a higher proportion of gross area irrigated under all crops (or profit from all crops) in the pre-interference period, then the farmer does not venture to invest in an additional well. Extending the same analogy, if the yield of groundwater in the pre-interference period is lower than that in the post-interference period, the farmer would venture to invest in an additional well.

One of the reasons for using the area irrigated or profit for all crops in the denominator is to allow for adjustment mechanism by farmers to attain pre-interference level of area or income. Towards this endeavour, the farmers may either increase or decrease the area under specific crop(s). In case this ratio considers the pre-interference area and post-interference area irrigated or profit for a particular crop, then we will be discounting the role of intra-farm adjustments. In addition, this may yield indeterminates like ∞, if the farmer has not devoted any area under say mulberry in the pre-interference period, while in the post-interference, as a coping mechanism to endure with the effect of interference, the farmer devotes some area for mulberry crop.

TABLE 1. HYPOTHESES FOR STUDYING THE INTERNALISATION OF EXTERNALITY

Variables (1)	Hypotheses (2)	Rationale (3)
Dependent variable Investment on additional well(s)	Farmer drills additional well in the event of well interference externality.	The farmer plays a game with groundwater availability with mini-max criterion, as he/she wants to sustain pre-interference level of economic status, thereby intending to minimise the maximum loss due to interference.
Independent variables (i) Size of holding (SIZE)	SIZE has positive influence on investment in groundwater resource.	Investment on groundwater well is a strategic management decision governed by the existing physical assets such as land. Such a magnitude of investment in groundwater will not be forthcoming below a certain minimum SIZE of holding, i.e. the threshold level of SIZE.
Ratios (ii) RGAC[1] (iii) RGAV[2] (iv) RGAM[3] (v) RGPV[4] (vi) RGPM[5]	If the ratio tends to unity, then the probability of drilling additional well is lower. Thus there is an inverse relation between each of the ratio variables and the dependent variable.	If the ratio of post-interference profit or area irrigated is close to the pre-interference profit or area irrigated, then the ratio will approach unity. In that case, there is no need for the farmer to invest in additional well, as the primary hypothesis is that the farmer drills additional well to at least be on the same pre-interference isoprofit curve. If the ratio is close to zero, then the post-interference profit or area irrigated is far lower than the pre-interference profit or area irrigated and that motivates the farmer to invest in additional well to be on the pre-interference isoprofit curve.
(vii) RAAF[6]	As this ratio tends to unity, the probability of drilling additional wells tends to increase.	The farmer tries his/her best not to lose the extent of area irrigated by well. Higher RAAF implies higher intensity of the effect of well interference which motivates the farmer to invest in additional well.
(viii) RAWY[7]	As this ratio tends to unity, the probability of drilling additional well tends to decrease.	If the ratio of groundwater yield in post-interference period to that in the pre-interference period tends to unity, this implies no reduction in groundwater yield due to interference and hence the farmer does not invest in additional well.

Notes: 1. RGAC: Ratio of gross irrigated area under cereals in post-interference period to gross area irrigated under all crops in pre-interference period.

2. RGAV: Ratio of gross irrigated area under vegetables in post-interference period to gross area irrigated under all crops in pre-interference period.

3. RGAM: Ratio of gross irrigated area under mulberry in post-interference period to gross area irrigated under all crops in pre-interference period.

4. RGPV: Ratio of gross profit from vegetable crops in post-interference period to gross profit from all crops in pre-interference period.

5. RGPM: Ratio of gross profit from mulberry in post-interference period to gross profit from all crops in pre-interference period.

6. RAAF: Ratio of net irrigated area affected by well interference to total irrigated area.

7. RAWY: Ratio of average water yield of interfered well to average water yield of well in pre-interference period.

Probability of Drilling Additional Wells

The probability that a farmer would invest in an additional well increased significantly with the size of holding, RGAV and RAAF, while it reduced with RGAM (Table 2). For every one per cent increase in the size of holding, the probability increased by 0.35 per cent. The RGAV (ratio of gross area irrigated under vegetables in post-interference period to gross area irrigated under all crops in pre-interference period) positively influenced the probability of drilling additional wells. For every one per cent increase in RGAV, *ceteris paribus*, the probability of drilling an additional well increased by 0.26 per cent. The post-interference increase in the area under vegetable crops induced the farmers to drill additional wells, because of the high profitability from vegetable crops. The RAAF (ratio of net area irrigated affected by well interference to total irrigated area) has a positive and significant influence on the probability of drilling additional wells. For every one per cent increase in RAAF, the probability of drilling an additional well increases by 10 per cent. The RGAM (ratio of gross area irrigated under mulberry in post-interference to gross area irrigated under all crops in pre-interference period) had an expected inverse relationship with the probability of drilling additional well. Mulberry provided greater profit margin with an assured market for farmers, and as the water requirement of mulberry is lower, for one per cent increase in RGAM, the probability of drilling additional well reduced by 0.36 per cent. The area under mulberry accounted for a major share (around 33 per cent) of the gross irrigated area.[5] At the macro level too, 70 per cent of the area under mulberry in Bangalore and Kolar districts is irrigated by groundwater. This shows that many farmers are devoting a major share of their area to mulberry in this region. The overall probability of drilling additional well is 0.87 and the odds ratio accordingly is 0.87/0.13 = 7, which implies seven chances in favour of drilling additional well to one chance of not drilling additional well.

TABLE 2. ESTIMATION OF LOGIT PROBABILITY OF DRILLING ADDITIONAL WELL

Variables (1)	Logit maximum likelihood estimator coefficient (2)	t-value (3)	Elasticity of probability (4)
1. Size of holding	0.38	2.62*	0.35
2. RGAC	-0.52	-0.19	-0.01
3. RGAV	11.63	2.32*	0.26
4. RGAM	-6.20	-2.69**	-0.36
5. RGPV	0.85	0.62	0.31
6. RGPM	0.35	1.23	0.03
7. RAAF	8.62	1.82*	10.02
8. RAWY	2.38	0.597	0.06
9. Constant	-8.37	-1.74*	
Log likelihood ratio test		24.85*	
Conditional probability of drilling additional well		0.87	
Mc Fadden R^2		0.48	

For the definition of variables, see *Notes* to Table 1.
* and ** Significant at 5 and 1 per cent level, respectively.

Willingness to Pay for Additional Well

As indicated by the Tobit analysis, the willingness to pay for additional well was Rs 48,370. For every one acre increase in the size of the holding, the WTPAW was estimated to be Rs. 14,122 (Table 3). Despite the high probability rate of well failure in the hard rock areas (=0.4), this reflects the capture of the resource despite uncertainty. The farmer whose well is interfered has different options to make additional investments by short and/or long run response (Table 4). This shows that the affected farmers may invest in several options available to them depending up on their capacity. For a specific farmer the willingness to pay is his/her marginal willingness to pay for additional well(s), and can be considered to represent the marginal externality cost curve (Figure 2). Considering the size of holding as an economic activity which determines the willingness to pay for additional well, the point E is the threshold level of holding from which point a farmer is willing to invest in additional well. The marginal externality cost curve increases along AEB as the size of holding increases. The area OAE is the negative marginal externality cost of drilling additional well, which implies a positive externality to the society, since farmers do not make investment on additional well till the point E, which is equal to 5.35 acres in the case of the size of holding.

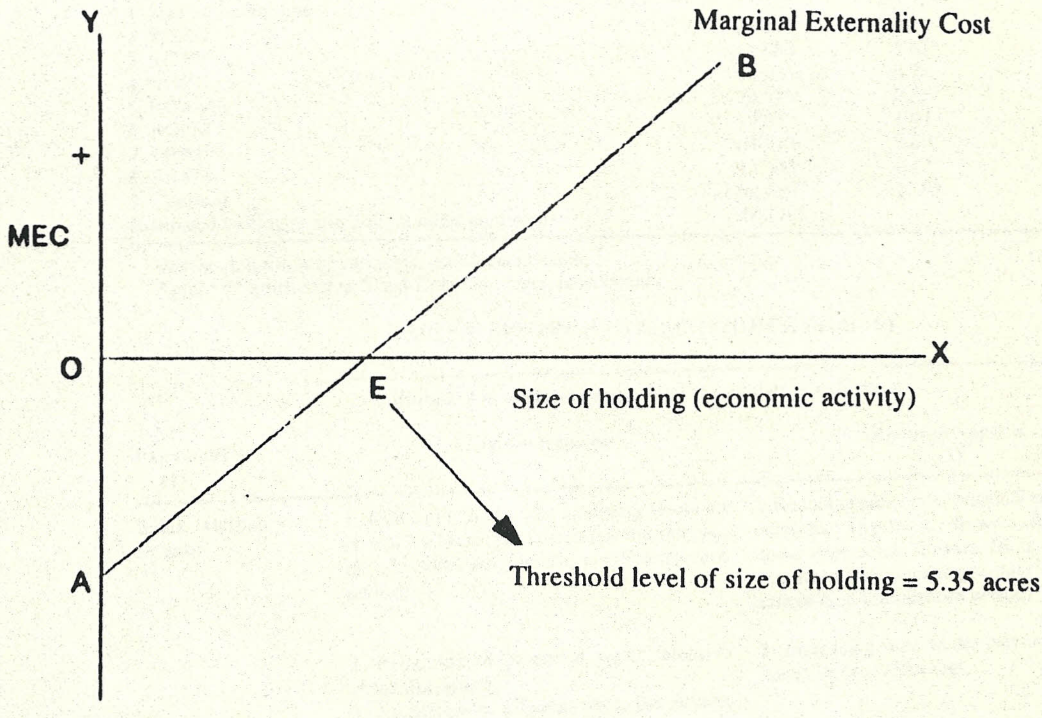

Figure 2. Marginal Willingness to Pay for Additional Well as Marginal Externality Cost Curve

TABLE 3. ESTIMATION OF WILLINGNESS TO PAY FOR ADDITIONAL WELL (TOBIT)

Variables (1)	Tobit maximum likelihood estimator coefficient (2)	t-value (3)	Conditional marginal willingness to pay for additional well (4)
1. Size of the holding	14,122	3.57**	14,122
2. RGAC	-21,247	-0.25	-212
3. RGAV	1,47,680	1.57*	1,477
4. RGPV	-23,003	-0.74	230
5. RGAM	29,885	0.51	209
6. RGPM	9,059	1.04	91
7. RAAF	61,412	0.60	614
8. RAWY	11,435	0.12	114
9. Constant	-1,68,680	-1.49*	-
Estimated willingness to pay for additional well	48,370		

For the definition of variables, see *Notes* to Table 1.
* and ** Significant at 5 and 1 per cent level, respectively.

TABLE 4. RESPONSE TO NEGATIVE EXTERNALITY

Externality (1)	Response to negative externality in groundwater extraction Long run response (2)	Short run response (3)
Stock externality (Static)	1. Increasing area under mulberry (from an area of 2.93 acres per farm in pre-interference to 3.56 acres per farm in post-interference period).	1. Reducing area under seasonal water intensive crops like vegetables, flowers, fruits (the area under vegetables, flowers, fruits fell by 50 per cent from 1.99 acres in pre-interference to 0.99 acre in post-interference period).
	2. Reduction of perennial water intensive crops like grapes. 3. Installation of efficient water use devices (investment upto Rs. 24,000 per acre on drip irrigation for mulberry) [Muralidhara *et al.*, 1993]. 4. Investment on over-ground water storage structures (earthen storage structure @ Rs. 1,977, concrete storage structure @ Rs. 15,600) [Nagaraj and Chandrakanth, 1993]. 5. Installation of high density polyethylene pipes instead of galvanised iron pipes to lift groundwater. 6. Installation of good IP set with the right HP (Rs.16,000 for 6 HP, 8 stage pump). 7. Competitive deepening of wells. 8. Drilling additional well(s) (@ Rs. 48,370). 9. Shifting to dryland farming.	2. Increasing area under seasonal low water intensive crops like ragi.
Flow (Dynamic) externality	1. Use of automatic starter (@ Rs. 450).	1. Alternating water intensive and low water intensive crops, depending upon availability of water.
	2. Competitive deepening of wells.	2. Co-operative arrangement.

IMPLICATIONS

Externalities in well irrigation in hard rock areas are intricate. Given the substantial incentives for groundwater withdrawal, and lack of groundwater institutions to monitor groundwater use for irrigation, intricate externalities in well irrigation continue to exist. With the high probability of drilling additional well of 0.87 and the high probability of well failure of 0.40, the predicament of negative externality gets exacerbated as farmers are involved in both causing and bearing the brunt of groundwater overdraft. The willingness to pay for drilling additional well to mitigate externality is Rs. 48,370, an indicator of the magnitude of negative externality for the farmer, which is uncompensated. In addition, the farmers cope with the negative externality by other means such as investment on over-ground water storage structures, growing low water intensive crops, adopting water saving devices and so on. Given the short productive life of the well, the fixed cost of investment on additional well assumes importance, even though the electrical energy to lift groundwater is provided free of cost. This calls for an economically sound costing methodology of well irrigation in hard rock areas.

The valuation of externalities is crucial in appreciating the positive role of subsidies and incentives which promote efficient groundwater use like drip or sprinkler irrigation system and the havoc played by subsidies like free electricity and soft loans for well irrigation which promote rapid exploitation of the precious groundwater resource. Considering the huge investment of Rs. 48,370 on an additional well, it may be worthwhile examining whether investment on structures like drip or sprinkler systems which aid in efficiently utilising the available groundwater is better than investment on a new well. Investment on a new well will not only increase the groundwater utilisation, but also is subject to a great risk of premature failure, as compared with investment on drip or sprinkler system, which may provide opportunities to efficiently utilise the available groundwater. Accordingly, in areas where cumulative well interference is apparent, provision of incentives like free electricity supply and providing soft loans for well irrigation may exacerbate the negative externalities, while provision of incentives like subsidies on sprinkler and/or drip irrigation systems, high density polyethylene pipes for lifting groundwater, capacitors in irrigation pumpsets, generate positive externalities, by way of reducing groundwater exploitation and cumulative well interference.

Received February 1996. *Revision accepted July 1997.*

NOTES

1. American Institute of Professional Geologists (1980), *Groundwater* (obtained from the Water Resources Library, University of California, Berkeley, U.S.A.)

2. Following studies undertaken under the guidance of the first author, supported by the Ford Foundation, New Delhi in the Department of Agricultural Economics, University of Agricultural Sciences, Bangalore, deal with negative externalities in groundwater in the hard rock areas: (1) B. Shivakumara Swamy (1995), *Economic Implications of Unsustainable Use of Groundwater in Hard Rock Areas of Karnataka*, M.Sc. (Agril.) Thesis (Unpublished). (2) M.S. Shyamasundar (1996), *Interplay of Markets, Externalities, Institutions and Equity in Groundwater Development - An Economic Study in the Hardrock Areas of Karnataka*, Ph.D. Thesis (Unpublished). (3) K.M. Sathisha (1997), *Resource Economics Study of Valuation of Well Interference Externalities in Central Dry Zone of Karnataka*, M.Sc. (Agril.) Thesis (Unpublished). Presently two more studies are in progress, determining the equity impacts due to the economic losses

due to interactive effects of irrigation wells. Preliminary results have provided evidence of interactive effects of well and with the inclusion of negative externality costs, the annual amortised cost of irrigation works out to around Rs. 14,000 per farm.

3. In case where a farmer did not invest in an additional well, the WTPAW may not necessarily be zero, as he/she might be willing to invest an amount below the cost of additional investment. Contingent valuation technique was not used to elicit this information and so the WTPAW of those farmers who did not make additional investment was not obtained and hence taken as zero. This is a limitation of the study.

4. If 'absolute difference' in the area irrigated (or profit realised) between the post- and pre-interference periods is used, it suffers from the problem of interpretation of negative or positive values. Instead, if the ratio of post-interference period area irrigated (or profit realised) to pre-interference period area irrigated (or profit realised) is used, then this overcomes the problem of negative values. Nevertheless, both the approaches have the limitation to the extent of non-removal of the inflationary effect. In addition, considering the real incomes was difficult, as the years and span between pre- and post-interference period differed from farmer to farmer.

5. Similar results are reported by Nagaraj and Chandrakanth (1995).

REFERENCES

Arun, V. (1994), *Estimation and Internalisation of Externalities in Groundwater Irrigation in Hardrock Areas of Karnataka,* M.Sc. (Agril.) Thesis, Department of Agricultural Economics, University of Agricultural Sciences, Bangalore (unpublished).

Ciriacy-Wantrup, S.V. (1969), *Resource Conservation: Economics and Policies,* Division of Agricultural Economics, University of California, Berkeley, U.S.A.

Dasgupta, Partha (1982), *The Control of Resources,* Harvard University Press, Cambridge.

Government of India (1996), *Information System Directorate Performance Overview: Water and Related Statistics,* Central Water Commission, New Delhi.

Muralidhara, H.R.; D.S. Gundu Rao; A.M. Sarpeshkar and R. Ramaiah (1993), *Is Drip Irrigation Viable for Mulberry Cultivation,* Department of Agricultural Engineering, University of Agricultural Sciences, Bangalore (Unpublished).

Nagaraj, N. and M.G. Chandrakanth (1993), "Electricity Pricing in Groundwater Irrigation in Hard Rock Areas of Deccan Plateau - Estimation of Willingness to Pay", Paper presented at the Workshop on Groundwater Management, India's Groundwater Challenge, VIKSAT, Ahmedabad, December 14-16.

Nagaraj, N. and M.G. Chandrakanth (1995), "Low Yielding Irrigation Wells in Peninsular India - An Economic Analysis", *Indian Journal of Agricultural Economics,* Vol. 50, No. 1, January-March, pp. 47-58.

Nagaraj, N.; M.G. Chandrakanth and Gurumurthy (1994), "Borewell Failure in Drought-Prone Areas of Southern India: A Case Study", *Indian Journal of Agricultural Economics,* Vol. 49, No. 1, January-March, pp. 101-106.

Singh, Chatrapati (Ed.) (1992), *Water Law in India,* The Indian Law Institute, New Delhi.