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GROUNDWATER OVER-EXPLOITATION, COSTS AND ADOPTION MEASURES IN THE CENTRAL DRY ZONE OF KARNTAKA

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GROUNDWATER OVER-EXPLOITATION, COSTS AND ADOPTION MEASURES IN THE CENTRAL DRY ZONE OF KARNATAKA*

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Abstract

The present paper analyses the consequences of groundwater overexploitation by using field level data collected from two distinct well irrigated areas of Karnataka. The study results show that the consequences arising out of groundwater overexploitation are severe in high well interference area compared to low well interference area. As a result, overexploitation of groundwater has differential impact on different categories of farmers in terms of cost of drilling, area irrigated per well and adoption of mitigation measures. The burden of well failure is more or less equally shared by all categories of farmers but small farmers are the worst victims of resource scarcity. The study suggests to maintain inter well distance to prevent 'resource mining' and to educate farmers to use light water crops. The institutional reform is necessary to restore surface water bodies to facilitate aquifer recharge.

Introduction

Resource scarcity is viewed at best as a major barrier to continued economic development, with its depressing implications for the economies of the developing countries. At the same time it was predicted that overexploitation of natural resource stocks would cause the total collapse of society during the early part of the twenty-first century (Rees 1990: 31). It seems clear that technological progress and market forces have not acted to reduce pressures on renewable resources as they have in

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the stock resource case (Johnson 1975; Dasgupta 1982). In the advanced economies higher real consumer incomes have not only increased the demand for a better quality of life and a cleaner environment but, coupled with rising levels of personal mobility, have intensified pressures on amenable natural resources such as water, forest and land resources.

Groundwater, as a natural resource, assumes a significant role either as a sole or as a supplementary source of irrigation. Although groundwater is conventionally regarded as a common pool resource, in fact, it is not so due to several reasons or for that matter cannot be treated as a open access resource primarily because its availability is restricted by various socio-economic and hydro-geological factors (Janakarajan 1997:1). Moreover, the over-use of groundwater poses a problem of externalities due to cumulative well interference problem. This is because a given aquifer can be shared by many and that creates the problem of competitive extraction (Janakarajan 1997). This problem is due to lack of efficient legal measures in checking or regulating its use (Singh 1992) and under-pricing for its true value (CVG 1997). In this context, this paper looks into the consequences of groundwater over-exploitation confining to irrigation sector in the central dry zone of Karnataka, India.

We start with a description of our study region and methodological issues. The results that are subjected to groundwater irrigation in the central dry zone of Karnataka are discussed in the subsequent section. In the light of the reported results, the concluding section proposes measures to prevent over-exploitation of groundwater resources in the context of the study area.

Study Area

The Central Dry Zone consists of 17 taluks with a total geographical area of 20,112.81 square kilometers. The rainfall ranges between 455.5 and 717.4 mm in the Zone. The elevation of the zone is 800-900m in major areas, 450-800m in the remaining areas. Table 1 provides details about the characteristics of the Zone.

Table 1: Characteristics of Central Dry Zone of Karnataka

Sl. No.	Characteristics	Particulars
1	Rainfall	Ranges from 455.5 mm to 717.4 mm
2	Elevation	800-900 in major areas, in remaining areas 450-800
3	Soil	Red sandy loam in major areas, shallow to deep black soil in remaining areas
4	Total geographical area (sq. kms)	20,112.81
5	Gross cropped area (hectares)	12,93,011
6	Net cropped area (hectares)	11,27,500
7	Total irrigated area (hectares)	2,51,270

The population density (ranges between 189 per sq. km and 235 persons per sq. km) in the study area is high compared to other zones in the state. Agriculture is the main occupation in the area. In the central dry zone as a whole, about 60 per cent of the working population is involved in the cultivation of land and another 25 per cent primarily as agricultural labourers. The literacy rate is on par with state average reflecting medium levels of social services and social development in the area.

Because of high population density, the average operational farm holding is considerably small. Farmland in the area is privately owned and a significant portion is farmed by the owners. Sharecropping, lease in and lease out are to the tune of less than 5 per cent. Land fragmentation is a widespread phenomenon.

Methodological Approach

Two taluks reporting high and low well interference problems were selected from the central dry zone in Karnataka state.[1] These taluks represent different levels of groundwater situation and reflect the overall situation in the agro-climatic zone. Nine villages were covered from two taluks in order to examine the overexploitation problem of groundwater resource.

The following steps were adopted in order to choose the taluks with the highest degree of well interference; interference of irrigation wells per hectare meter (ham) of net groundwater availability = (No. of IP sets or wells/utilisable GW for all purposes in ham) for each taluk; calculation of the ratio involved the following steps (Shivakumaraswamy and Chandrakanth 1997). Given below are the steps used to calculate index of well interference.

Step 1 **:** In the first step, irrigation pump sets (IP) were considered as a proxy to irrigation wells and borewells installed.

Step 2 **:** Net annual groundwater availability was considered for calculating index of cumulative well interference ratio in each taluk. Net annual groundwater availability in hectare meter indicates the utilizable quantum of groundwater for all purposes in a particular year for each taluk. The data pertained to 2004-05.

Step 3 **:** By considering cumulative number of wells and net annual groundwater availability, cumulative well interference index was calculated, which explains the number of wells per hectare meter of utilizable groundwater in each taluk. This can be written as:

Index of Cumulative Well Interference (ICWI) = (No. of IP sets or wells/Utilizable groundwater for all purposes in ham) for each taluk.

Step 4 **:** The taluks were then arranged in descending order of the magnitude of the above index. The taluks were later classified according to the agro-climatic zones of the State in order to obtain variability in groundwater use across crop types, soil types and climatic types.

Among the Agro-climatic Zones, eastern dry zone topped with respect to ICWI, followed by central dry zone, northern dry zone and southern dry zone, which have the magnitude of **ICWI** above ***one.*** However, we decided to choose the taluk which topped with respect to ICWI in one out of ten agro-climatic zones and which did not have substantial surface irrigation projects. The agro-climatic zone chosen was Central Dry Zone. The selected taluks were Madhugiri and Hosadurga in the Central Dry Zone. The taluks were selected based on highest and lowest magnitude of ICWI respectively.

For the selection of villages in selected taluks in the selected Zones, the village-wise availability of groundwater for irrigation was computed by using a ratio. The ratio was calculated as follows:

(Net sown area of the village/net sown area for the taluk) x (Utilisable groundwater of the taluk).

Villages were then sorted out in descending order of the magnitude of the above ratio. The villages were later selected in order to obtain variability in groundwater use across crop types, soil types and climatic types. The selected villages are representing high and low magnitude of groundwater availability in the respective taluks.

The data collection was done at two levels. At the first level, Participatory Rural Appraisal (PRA) technique was used to select respondents in all the villages. At the second level, detailed information regarding various aspects of well irrigation was collected using a detailed questionnaire for households whose wells had been interfered. This study comprised a group of villages where irrigation wells suffered from cumulative well interference (hereafter HWIA) and another group of villages where interference problem did not lead to high well failure (hereafter LWIA).

Basic features of the study villages were almost similar in terms of occupational pattern, cropping pattern, infrastructures and social services. In all the villages, small and marginal farmers were in majority. There was high concentration of borewells as well as openwells in HWIA compared to LWIA. The area irrigated was less than 25 per cent of the total cultivable land in all the villages except in Heggere, where the area irrigated to total cultivable land was merely 27 per cent.[2] The major livelihood source was agriculture for over 90 per cent of the people in all the sample villages. The basic features of the sample villages have been given in Table 2.

Table 2: Basic features of sample villages

Village	Total no. of HHs	Av. HH size	Av. farm size (Ha)	Area irrigated (Ha)	Availability of tanks (Nos.)	Major liveli hood source**$**
LWIA						
Adrikatte	115	4.4	5.11	51.88 (14.9)	-	Agriculture
Heggere	400	5.2	2.56	405.16 (26.9)	2	Agriculture
Huralihalli	50	5.5	6.29	30.86 (9.5)	-	Agriculture
Marabagatta	300	5.9	4.75	47.88 (19.7)	1	Agriculture
HWIA						
Chandragiri	183	5.5	1.62	231.79 (23.1)	-	Agriculture
D V Halli	124	6.5	2.05	22.63 (8.3)	-	Agriculture
Garani	375	6.8	3.12	130.84 (13.5)	1	Agriculture
Kambadahalli	85	5.4	4.60	8.36 (4.9)	1	Agriculture
Madenahalli	100	6.2	2.67	23.19 (13.5)	-	Agriculture

Source: Primary survey.

Note: Figures in parenthesis indicate percentage to area irrigated; GW: Groundwater.

$ Livelihood source is considered as a source where it provides about 75 per cent of the needs of the total requirements of the household.

Results and Discussions

Characteristics of Groundwater Irrigation

The groundwater irrigation is characterized by sole ownership rights and control on its access which are in quite contrast to traditional community managed or state managed surface irrigation systems. Development of groundwater based irrigation has created way for intensive multi-season agriculture. Since surface irrigation sources and traditionally used tanks have lost thier irrigation potentiality due to various reasons[3], one can see rapid growth in groundwater irrigation and resulting in emergence of groundwater as a crucial productive resource.

Prior to green revolution, the major sources of irrigation were traditional tanks, streams and open wells. With decline in water levels, the depth of open wells could not be restricted to the weathered zone and had to pierce the underlined fractured zone, the excavation of which was through manual rendering the process slow and expensive. Farmers, therefore, preferred boring from the bottom of open wells instead of conventional excavation. Such dug-cum-borewells allowed initially the use of centrifugal pumpsets installed on open wells. However, dug-cum-borewells were of limited use because water levels soon declined below the suction limit of centrifugal pumpsets, forcing the farmers to switch over to deeper surface borewells and install submersible pumpsets. This commenced in the early 1980s and marked an important phase of groundwater development in the state (Rao 1992: 2). Further, the easy access to technology and credit availability was the major influencing factor for the growth of borewells in semi-arid regions of the state. This, coupled with the availability of subsidized electricity for agriculture purpose, multi-crops with multi-season were made possible leading to surplus production. All these contributed to the shifting of groundwater structures from dug-cum-borewells to deeper surface borewell technology.

Type and Ownership of Wells across Landholding Size

Landholding size seems to be a major factor for owning different type of groundwater structures. Table 3 demonstrates that as the landholding size increases the preference to have borewell technology increases and *vice versa*. It is clearly visible in the case of LWIA, where the proportion of borewells is in increasing trend as we move towards larger landholding sizes. The ownership of different types of groundwater structures in HWIA gives a different picture as this is highly affected by well interference problem.

Evidently, the groundwater structures owned by small farmers in HWIA are due to the reason that a majority of them are late comers in the resource extraction activity. In this situation, small and marginal farmers are unable to strike water as this area is already suffering from acute well interference problem. In the course of competition, even if they are able to mop the capital required for additional well, they would have to bear greater risk of not striking adequate groundwater in this area. This has made small farmers to have more wells as they are unable to deepen their existing wells because of high equipment cost.

Table 3: Distribution of Wells across Landholding Size

Landholding size (Ha)	No. of BW	No. of DW	No. of DCBW	Total wells	% of wells dried up	No. of Bw	No. of DW	No. of DCBW	Total wells	% of wells dried up
	LWIA					HWIA				
Marginal (up to 1)	11	0	0	11	18.2	27	14	5	46	76.1
Small (1.01 to 3)	52	3	0	55	29.1	168	41	36	245	78.8
Medium (3.01 to 5)	58	4	0	62	41.9	49	17	3	69	65.2
Large (more than 5)	99	4	1	104	51.9	28	6	4	38	50.
Total	220	11	1	232	42.2	272	78	48	398	73.4

Source : Primary survey

Note : BW – Borewell; DW – Dugwell; DCBW – Dug-cum-borewell

Percentage of dried wells represents all types of completely failed wells.

The burden of groundwater overexploitation in terms of failed wells is equally distributed among all categories of farmers in HWIA (Table 3). In LWIA, small farmers are less affected compared to medium and large farmers. This is on account of resource availability and ownership of land. The availability of resource for drilling wells allows them to have more number of wells and in the process, the extraction of groundwater influences the high rate of well failure.

The openwells are the first causality of overexploitation of groundwater. This has been evidenced clearly from our survey data. The causality of groundwater overexploitation in terms of defunct wells is highest in both the areas irrespective of the degree of well interference problem. Therefore, none of the openwells and DCBW is functional. At the surface it appears that the numbers of wells are high but it is not so in terms of functioning wells.

After the open wells become dry, the concern of the farmers shifts to restoration of well irrigation at any cost. Oblivious to the risk involved, farmers incur heavy expenditure on drilling borewells, most of them making repeated attempts. Even in respect of successful borewells many farmers have had to incur expenditure in deepening borewells because the borewells which succeeded initially were dry after running for a few years. This process has led to owning more number of wells to sustain crops.

In the study area, the ownership rights over groundwater structures viz., borewells and open wells are enjoyed by a sole owner but not by joint well owners. This is of fundamental importance of understanding emerging groundwater problems and potential solutions because it has become a central point of overexploitation. It accelerates the rate of extraction of groundwater as they enjoy the ownership rights as well as freedom to extract groundwater as and when required. The survey conducted in 9 villages show that about one-third of large farmers owned nearly 50 per cent of wells in LWIA (Table 4). Similarly, in HWIA, the maximum number of wells owned by small farmers is an indication of high well failure due to well interference problem.

Table 4: Ownership of Wells across Size Class of Landholding in LWIA and HWIA

Landholding size (Ha)	Number of well owners	Total number of wells owned	Functioning wells (%)	Total extent of land irrigated (ha)	Average extent irrigated area per well (ha)#
Marginal Farmer	10	11	81.8	5.58	0.62
Small Farmer	37	55	70.9	44.08	1.13
Medium Farmer	26	62	58.1	51.16	1.42
Large Farmer	29	104	48.1	106.11	2.12
LWIA	**102**	**232**	**57.8**	**206.93**	**1.54**
Marginal Farmer	15	46	23.9	6.99	0.64
Small Farmer	73	245	21.2	73.43	1.41
Medium Farmer	22	69	34.8	36.54	1.52
Large Farmer	13	38	50.0	38.05	2.00
HWIA	**123**	**398**	**26.6**	**155.01**	**1.46**

Source : Primary survey

Average extent of irrigated area is calculated for functioning wells only and this includes area irrigated through water markets as well.

Past studies have revealed that larger the land area owned, greater was the possibility of striking groundwater (Janakarajan and Moench 2006). In this respect, the scope of sustaining groundwater irrigation is far better for large land owners compared to small holders. But it is difficult to predict for how long they will sustain in the course of competitive deepening. In this context, it is important to note that while the threat of getting eliminated from the race of competitive deepening is seemingly just around the corner for the resource-poor farmers, the resource rich farmers have the capability of sustaining the adverse effects of competitive deepening. This is simply because the resource rich farmers are not constrained to the same extent as resource poor farmers in mobilizing finance for well drilling or well deepening activities.

However, the sole ownership is the indication of the property rights claimed over groundwater. The operation of the law of inheritance has perpetuated the problem of sole ownership of land. With the problem of fragmentation of land, every single farmer who can afford to drill borewell is now enjoying the property rights over groundwater by extracting substantial quantity of groundwater. In the event of competitiveness to bring more area under irrigation, small and marginal farmers tend to have experimented with drilling more wells even though they did not strike adequate quantity of groundwater. Therefore, the area irrigated per well by small and marginal farmers is comparatively low with medium and large farmers (Table 4). For instance, both in LWIA and HWIA, the area irrigated per well in the case of marginal farmers is less than 1 ha and in the case of small farmers it is less than 1.5 ha. But in the case of large farmers the area irrigated per well is more than 2 ha in both the conditions.

To sum up, medium and large farmers are enjoying ownership rights over groundwater structures as they are able to remedying the declining groundwater table by deepening the wells. But small and marginal farmers are in a regime where water table is retreating progressively which has made them helpless. The position of these farmers is quite vulnerable for, in order to be able to remain in the race of competitiveness of groundwater extraction, they have to keep on investing in well drilling and deepening activities without any assurance of striking an aquifer. While a few are successful in striking groundwater, a large majority fail.

***Well density*[4]:** The well density per unit of area is 1.2 in HWIA, which is very high as compared to LWIA of 0.5 (Table 5). Higher number of borewells per unit of area in HWIA indicates high well failure rates and consequently more investments on borewells due to high well interference problem. Higher well density is a greater threat to the sustainability of groundwater resources. Thus, if proper isolation distance is not maintained it is bound to create cumulative well interference problem. As a result, the surrounding wells get dried up and subsequently leading to more investments on additional wells. In case of HWIA, the well density is very high reflecting the un-sustainability of the groundwater resource. Though the well density in terms of increased number of wells indicates wider access, the resource needed to own a well and pump is beyond the capacity of small and marginal farmers considering the high capital cost.

Table 5: Well Density in LWIA and HWIA

Villages	**Land (ha)**	**Well density**	**Area per well (ha)**
Adrikatte	122.82	0.5	1.9
Heggere	89.87	0.7	1.4
Huralihalli	75.5	0.6	1.6
Marabgatta	147.51	0.4	2.4
LWIA	**435.7**	**0.5**	**1.9**
Chandragiri	46.58	2.7	0.4
D. V. Halli	43.12	1.2	0.8
Garani	117.06	0.9	1.1
Kambadahalli	65.3	0.6	1.7
Madenahalli	53.38	1.3	0.8
HWIA	**325.44**	**1.2**	**0.8**

Source: Primary survey

The village-wise analysis indicates that the villages in LWIA are having lower well density compared to HWIA. In HWIA, the well density is high in scarcity villages compared to other villages (Table 5). It is not surprising to mention that the villages where high well density is reported the area per well is also low. This indicates the problem of cumulative well interference as the small size of land accommodating larger number of wells and extracting water beyond the sustainable rate.

Area irrigated: Water yielding characteristics and area irrigated by wells vary among the villages which are affected by severe well interference problem and those which are not. For instance, in LWIA, nearly 37 per cent of the wells are irrigating more than 10 acres gross compared to 25.4 per cent of the wells that are irrigating the same area in HWIA (Table 6). Similarly, less than 15 per cent of the wells are irrigating more than 5 acres of net irrigated area both in LWIA and HWIA (Table 7). This implies that the gross irrigated area (GIA) and net irrigated area (NIA) of LWIA is high due to low well interference and the cropping pattern. However, in HWIA, the area irrigated per well (both GIA and NIA) appears to be low due to low yield rate of aquifers and mining the aquifers beyond the threshold level.

Table 6: Gross Area Irrigated Per Well in LWIA and HWIA

GIA (Acres)	LWIA					HWIA						
	Adrikate	Heggere	Huralihalli	Marabagatta	Total	Chandragiri	D V Hall	Garani	Kambadahalli	Madenahalli	Total	Grand total
0.01-2.5	1	1	0	3	5 (3.73)	3	3	10	4	7	27 (25.5)	32 (13.3)
2.51-5.0	8	9	0	9	26 (19.4)	4	12	13	4	1	34 (32.1)	60 (25.0)
5.01-7.5	9	18	2	10	39 (29.1)	3	6	9	4	1	23 (21.7)	62 (25.8)
7.51-10.0	7	1	2	5	15 (11.2)	0	4	4	1	1	10 (9.43)	25 (10.4)
> 10.0	9	17	12	11	49 (36.6)	3	0	5	4		12 (11.3)	61 (25.4)
Total	34	46	16	38	134 (100)	13	25	41	17	10	106 (100)	240 (100)

Source: Primary survey

Note: Gross area irrigated has been calculated only for those wells which are functional.

Scarcity villages: Adrikatte and Marabgatta in LWIA and Chandragiri, Garani and Madenahalli in HWIA

Figures in parentheses indicate percentages to total.

Table 7: Net Area Irrigated Per Well Across Villages in LWIA and HWIA

NIA (Acres)	LWIA					HWIA						
	Adrikate	Heggere	Huralihalli	Marabagatta	Total	Chandragiri	D V Hall	Garani	Kambadahalli	Madenahalli	Total	Grand total
0.01-1.0	3	4	0	3	10 (7.5)	4	2	10	3	3	22 (20.8)	32 (13.3)
1.01-2.5	15	24	2	17	58 (43.3)	6	13	13	5	4	41 (38.7)	99 (41.3)
2.51-5.0	9	17	10	12	48 (35.8)	1	10	14	7	3	35 (33.0)	83 (34.6)
5.01-7.5	5	1	1	3	10 (7.5)	2	0	4	1	0	7 (6.6)	17 (7.1)
> 7.5	2	0	3	3	8 (6.0)	0	0	0	1	0	1 (0.9)	9 (3.8)
Total	34	46	16	38	134 (100)	13	25	41	17	10	106 (100)	240 (100)

Source: Primary survey

Note: Net area irrigated has been calculated only for those wells which are functional.

Scarcity villages: Adrikatte and Marabgatta in LWIA and Chandragiri, Garani and Madenahalli in HWIA

Figures in parentheses indicate percentages to total

The cumulative well interference induced water scarcity comes out clearly from Tables 6 and 7. For instance, in LWIA, area irrigated per well is higher than that of gross area irrigated per well in HWIA. In HWIA, gross area irrigated per well is declining as we move towards higher end. The difference is quite sharp between scarcity villages and non-scarcity villages in terms of gross irrigated area and net irrigated area. Such difference in the area irrigated by wells between scarcity and non-scarcity villages in HWIA is very much reflected in crop productivity as well. We learn from our survey that a majority of the farmers in HWIA have given up arecanut plantation, which they depended upon earlier due to severe water scarcity problem. This is a clear indication of negative externality which poses severe threat to the welfare of peasant families in terms of loss of income, food and employment insecurity and migration[5].

Consequences of Groundwater Over-exploitation

Groundwater depletion is by far a most widely debated issue in the resource economics literature. Groundwater depletion problems are related to the question of resource management and the coalition of powerful property owners protecting their interests, under a capitalist society. The overexploitation of groundwater and its social consequences are the result of certain processes of development in irrigated agriculture that are occurring at the cost of depletion of aquifers and sustainable farming systems. The state intervened initially through agrarian reforms, and later by providing credit facilities and supporting marginalized groups to have irrigation facilities by implementing Million Well Schemes, Ganga Kalyan Yojana and politically influenced free power supply etc. All these led to rise in groundwater structures, shifting cropping pattern towards water intensive crops as well as resource abuse to a larger extent by overexploiting the aquifer.

The distinctive impact of irrigation in general, and groundwater irrigation in particular, on farming has begun to emerge more clearly and recognizably where irrigation permits extension of cultivation to additional seasons (Rao 1978). This provides farmers to benefit from surplus production which otherwise would not have been possible with single crop season. As a result, groundwater has become a chief source of irrigation primarily in arid and semi-arid areas and at the same time several problems have cropped up due to heavy pumping.

Growth, Depth and Cost of Borewells

As indicated above, growth of groundwater structures (wells) is associated with many factors. Falling water levels and competition among farmers have major implications for the growth of wells in the study area. This has had a variety of impacts. First, there has been a change in the type of wells. Traditional openwells/dug-cum-borewells could not be used when water levels fell and new technologies for both wells and pumping proliferated in recent decades. Now, large numbers of defunct openwells have turned as storage tanks in the wake of infrequent power supply and voltage fluctuation.

The growth of wells seems to be high in HWIA compared to LWIA (Table 8). This fast growth is because of frequent well failure problem. Since HWIA is suffering from cumulative well interference problem, frequent well failure and declining yield rate are quite obvious in this area. Similarly, the depth of borewells is increasing constantly with the number of borewells both in HWIA and LWIA, but the severity is high in HWIA. Table 8 reveals that the depth of borewells in HWIA is always higher than that of LWIA. The difference is almost two times. This is a clear indication of competitive extraction behaviour of farmers in HWIA.

Declining groundwater table as well as availability of a variety of drilling technologies have major implications on the cost of obtaining access to groundwater. The cost of drilling borewell is much lower in LWIA compared to HWIA because water tables are higher. Importantly, the water required by the crops is less in LWIA compared to HWIA due to cropping pattern. This reduces the pressure on groundwater resource and hence, declining cost of drilling.

Table 8: Details of Borewells in HWIA and LWIA

Particulars	Before 1985	1985-90	1991-95	1996-2000	2001-07
LWIA					
Total No. of borewells	8	12	36	80	84
Average depth (ft)	154	164	187	179	215
HP used	4.3	4.91	4.55	4.22	4.52
Initial failure of wells (per cent)	0	8.3	22.2	38.75	33.33
Investment on wells (Rs. in current prices.)					
1. Drilling cost	7,022	9,338	8,671	8,968	10,890
2. Investment on additional well	7,505	8,812	8,188	9,853	11,273
HWIA					
Total No. of borewells	9	13	72	85	94
Average depth (ft)	281	404	373	383	490
HP used	8.1	8.5	8.5	9.5	9.5
Initial failure of wells (per cent)	11.11	0	22.22	30.58	26.59
Investment on wells (Rs in current prices.)					
1. Drilling cost	15,447	13,525	16,422	17,836	24,582
2. Investment on additional well	11,595	22,856	17,775	18,775	26,114

Source: Primary survey

The problem of initial failure of wells also indicates the severity of groundwater overexploitation in both the areas (Table 8). As the number of wells increases, the isolation distance between wells decreases. As a result, the cost of drilling increases considerably, especially in HWIA, where isolation distance between wells decreases severely leading to problem of well failure. Thus, the investment on additional well is increasing over time and it is considerably high in HWIA (Table 8). For instance, investment on additional well in LWIA was Rs. 7,505 prior to well interference period i.e., 1985, while it was Rs. 11,595 in HWIA during the same period. Gradually, investment on additional wells started rising in the event of high rate of well failure due to declining water table. Consequently, the investment on additional wells is increasing sharply in HWIA (more than two times during 2001-07).

The major implication of cumulative well interference is the ever increasing cost. Our survey results show that the cost incurred on well drilling by individual farmers is quite high in HWIA as compared to LWIA. In particular, cost incurred on well drilling looks quite disproportionate to landholding size (Table 9). For instance, the amount spent per well located in the HWIA works out to Rs. 17,152 compared to Rs. 9,624 in LWIA. Further, the rate is disproportionate in the cost of drilling well as reflected in terms of landholding size as well. The current average cost of drilling per well is highest among small and marginal farmers in HWIA compared to their counterparts in LWIA. This implies that the implications of cumulative interference problem on access to resource are severe in HWIA.

Table 9: Cost of Drilling Per Well across Landholding Size (at current prices)

Landholding size (ha)	LWIA				HWIA			
	Total No. of farmers	Av. depth (ft)	Av. cost per well (Rs.)	Av. HP	Total No. of farmers	Av. depth (ft)	Av. cost per well (Rs.)	Av. HP
Marginal Farmer (Up to 1)	10	197	10,978 (11)	4.3	15	490	21,583 (46)	10.3
Small Farmer (1.01 to 3.0)	37	192	9,392 (55)	4.4	73	426	22,723 (242)	8.9
Medium Farmer (3.01 to 5.0)	26	186	9,125 (62)	4.7	22	360	19,220 (69)	9.2
Large Farmer (More than 5.0)	29	195	9,900 (104)	4.4	13	393	18,509 (38)	8.7
Total	102	192	9,624 (232)	4.5	123	417	21,573 (398)	9.1

Source: Primary survey

Note: Figures in parentheses indicate number of wells (all types of wells).

Falling water levels and competition among farmers have major implications for the resource extraction technology that can be used. With changing technology for the extraction of groundwater from deep aquifers and use of high power motors have huge impact on energy demand. Until 1990s, manually lifting device eg., *yetha* was the main means of water extraction from openwells. That is now not in practice due to change in types of wells that can be used for irrigation in the wake of declining water tables. Dug-cum-borewells were used for some times with low capacity (3.5 HP) pumpsets. Later, with the availability of borewell technology coupled with declining water tables, high horse power is being used in relation to depth.

Such steep rise in horse power used disturbed the balance between groundwater recharge and extraction resulting in the decline of water levels in areas characterized by high well density. A sharp decline in the water tables and reduced thickness have resulted in lower aquifer transmissibility. This implies that the rate of pumping should be reduced significantly to stabilize the water tables. Unless proper measures to control over pumping of the resources are undertaken in future, even with the same rate of pumping, the rate of water table decline will be much faster. This observation corroborates with the findings of earlier studies in the semi-arid areas (Janakarajan and Moench 2006).

Similarly, competitive deepening has created huge havoc among farmers by preventing groundwater irrigated agriculture for some time. Declining water levels have encouraged increases in use efficiency. Until 1980s, open channels were used for conveying water from wells to the fields. Now, the farmers often use underground pipelines and hose pipes. Over-ground storage tanks are common in HWIA to store water due to low voltage power supply as well as frequent power cut. Therefore, high well and equipment costs disproportionately affect small farmers. While large farmers have the resources to survive unsuccessful investments in well drilling and well deepening, for a small farmer the losses are often unsustainable.

Incidence of Well Failures

The total number of wells distributed across villages is given in Table 10. It is clear from the table that the total number of wells owned was more than one and half times for HWIA (398) as compared to LWIA (232). It was observed that around 73 per cent of the wells (borewells+openwells) had failed in HWIA whereas in the LWIA the proportion of total failed wells was around 42 per cent. For instance, in HWIA, around 61 per cent of failed wells belonged to borewell category. Similarly, in LWIA, the proportion of completely failed borewells to total borewells was about 40 per cent. On the other hand, all the open wells and dug-cum-borewells have become defunct in both the areas due to cumulative well interference problem.

In the LWIA, the proportion of still functioning wells is around 58 per cent compared to 26.4 per cent in HWIA. This negative externality could link with social and economic condition of the rural agrarian livelihood system. The most visible implications of well failure problem are increasing cost on additional wells, cost on well deepening, reduction in area per well and loss of gross and net income from agriculture.

Considering the well failure due to well interference and their impact in the HWIA, the burden of openwell falls equally on both small and large farmers, as more than 50 per cent of the failed wells in both categories of wells were owned by small farmers. Hence, the concern towards the small and marginal farmers due to interference negative externality is substantiated in the situation where interference is apparent. In addition, the ability of small farmers in bearing the brunt of well failure is limited by the size of their holding, savings, re-investment and economic resilience potentials. Even if they are able to mop the capital required for additional well, they would bear greater risk of not striking groundwater since their area is already suffering from acute well interference problems (Shivakumaraswamy and Chandrakanth 1997).

Table 10: Incidence of Well Failure across Landholding Size

Landholding size (ha)	Bore-wells	Open wells	Completely failed borewells	Completely failed open wells@	Total failed wells	Total wells func-tioning	Total number of wells
Marginal Farmer (up to 1) N=10	11 (100)	0 (0.0)	2 (18.2)	0	2 (18.2)	9 (81.8)	11
Small Farmer (1.01 to 3.0) N=37	52 (94.5)	3 (5.5)	13 (25.0)	3	16 (29.1)	39 (70.9)	55
Medium Farmer (3.01 to 5.0) N=26	58 (93.5)	4 (6.5)	22 (37.9)	4	26 (41.9)	36 (58.1)	62
Large Farmer (More than 5.0) N=29	99 (95.2)	5 (4.8)	50 (50.5)	5	55 (52.9)	49 (47.1)	104
LWIA (N=102)	**220 (94.8)**	**12 (5.2)**	**87 (39.5)**	**12**	**99 (42.7)**	**133 (57.3)**	**232**
Marginal Farmer (up to 1) N=10	27 (58.7)	19 (41.3)	17 (63.0)	19	36 (78.3)	10 (21.7)	46
Small Farmer (1.01 to 3.0) N=37	168 (68.6)	77 (31.4)	116 (69.0)	77	193 (78.8)	52 (21.2)	245
Medium Farmer (3.01 to 5.0) N=26	49 (71.0)	20 (29.0)	25 (51.0)	20	45 (65.2)	24 (34.8)	69
Large Farmer (More than 5.0) N=29	28 (73.7)	10 (26.3)	9 (32.1)	10	19 (50.0)	19 (50.0)	38
HWIA (N=123)	**272 (68.3)**	**126 (31.7)**	**167 (61.4)**	**126**	**293 (73.6)**	**105 (26.4)**	**398**

Source: Primary survey

Note: Figures in parentheses in column 2, 3, 6 & 7 indicate percentage to total wells; in column 4 indicate percentages to total number of borewells.

@ All the openwells and dug-cum-borewells have failed in the study area, hence we have consider them as openwells for general understanding.

The proportion of borewells owned in LWIA by small farmers is low due to heavy investment for borewell. However, it is often portrayed as only affordable by the resource rich farmers. Our data do not support this. Although small and marginal farmers own less number of wells in LWIA, this proportion is significantly high in HWIA. As a result, the groundwater *resource mining* is taking place. This suggests that the extraction of groundwater resource is precarious in this area to the extent that even the low water required plantation crops have also gone dry due to non-availability of timely water to the crop growth[6]. The following are the observations from Table 10:

- The burden of well failure is more or less equally shared by all farmers but small farmers are the first victims of *resource mining* in HWIA.
- The burden of well failure is comparatively less in LWIA.
- Only about 26 per cent of the wells are functional in HWIA. The proportion of functional wells in LWIA is about 57 per cent indicating thereby that, although the problem of interference is moving towards peak, the problem of well failure is less than that of HWIA.

Declining Water Markets

Groundwater aquifers in the central dry zone are characterized by hard rocks and have low potential recharge capacity. These aquifers get generally recharged through monsoon rainfall. Low levels of yields, low storage and the high risky nature of hard rock aquifers have important implications for the nature of water markets. Groundwater markets are disappearing in hard rock areas where well yields are low and often vary widely across seasons. In this situation, surpluses are too smaller and tend to vary across seasons and locations (Janakarajan and Moench 2006).

Past studies on water markets have shown that since power is charged at a flat rate based on pump horsepower, the marginal cost will be zero and sale of any surplus at any rate reduces average costs. In many such cases, the bargaining position of both buyers and sellers is relatively equal. Anantha and Sena's (2007) study in West Bengal reveals that diesel pump owners sell water to recover historical investment made on the equipments while electric motor owners sell to reduce annual average costs of operation and maintenance. In these situations, the bargaining power of both sellers and buyers is equal. However, the situation in hard rock areas is different from that of water abundant regions in India.

In the study area, the size of water market is insignificant and is based on mutual understanding (Table 11). In most of the cases water sale is on kind transaction. Importantly, market exists between neighbourhood farmers or relatives whose land is adjacent. In these instances, the market operates on the basis of social obligations. Therefore, the purpose of profit maximization or reduction in average cost is negligible in all the situations.

Table 11: Distribution of Farmers by Water Selling Activity

Area	Water sale		Total
	Yes	No	
LWIA	2 [2.0] (11.8)	100 [98.0] (48.1)	102 [100] (45.3)
HWIA	15 [12.2] (88.2)	108 [87.8] (51.9)	123 [100] (54.7)
Total	17 [7.6] (100)	208 [92.4] (100)	225 [100] (100)

Source: Primary survey

Note: The figures in parentheses indicate row and column-wise percentages to total respondents, respectively.

Increasing water scarcity poses severe threat to the existence of water markets in the study area. In this situation, well owners cannot get surplus water to sell it to potential buyers who are in need. Thus, groundwater overexploitation is a major impediment in improving land and water productivity.

Coping Mechanism

To mitigate the groundwater scarcity problem most of the farmers have adopted coping mechanisms and these mechanisms have entailed sizable investments. These coping mechanisms include well deepening, additional well drilling, adoption of water saving technologies such as drip irrigation, shifting cropping pattern etc.

Well Deepening/Drilling Additional Wells

Well deepening or drilling an additional well is a common phenomenon in HWIA compared to LWIA. Drilling an additional well being one of the capital intensive mechanisms is adopted by the large farmers (Table 12). The small and marginal farmers are constrained to adopt these measures due to their poor capital base.

Table 12: Distribution of Farmers by Drilling Additional Well

Landholding size (ha)	LWIA		HWIA		Total	
	Total No. of farmers	No. of farmers who have drilled additional well	Total No. of farmers	No. of farmers who have drilled additional well	Total No. of farmers	No. of farmers who have drilled additional well
Marginal Farmer (Up to 1)	10 [40.0] (9.8)	1 [6.7] (1.8)	15 [60.0] (12.2)	14 [93.3] (12.5)	25 [100] (11.1)	15 [100] (8.9)
Small Farmer (1.01 to 3.0)	37 [33.6] (36.3)	12 [15.6] (21.4)	73 [66.4] (59.3)	65 [84.4] (58.0)	110 [100] (48.9)	77 [100] (45.8)
Medium Farmer (3.01 to 5.0)	26 [54.2] (25.5)	18 [46.2] (32.1)	22 [45.8] (17.9)	21 [53.8] (18.8)	48 [100] (21.3)	39 [100] (23.2)
Large Farmer (More than 5.0)	29 [69.0] (28.4)	25 [67.6] (44.6)	13 [31.0] (10.6)	12 [32.4] (10.7)	42 [100] (18.7)	37 [100] (22.0)
Total	102 [45.3] (100)	56 [33.3] (100)	123 [54.7] (100)	112 [66.7] (100)	225 [100] (100)	168 [100] (100)

Source: Primary survey

Note: Figures in parentheses indicates row and column-wise percentages to total.

Most of the large farmers have adopted coping mechanisms on a large scale compared to small holders. All the large farmers in the area have gone for additional well due to the failure of previous well. More than 75 per cent of the small and marginal farmers have ventured in drilling additional well in HWIA compared to their counterparts in LWIA. This clearly indicates the precarious condition of the small farmers on account of declining water tables. The transfer of water from the far off places to the arecanut garden was adopted by large farmers in HWIA.[7]

The field observation during data collection confirms that most of the small farmers who had gone for additional well, mobilized capital from their friends and relatives since institutional finance was not coming fourth.[8]

Adoption of Drip Irrigation

The resource conservation through water saving technologies is taking place though it is never than before situation. Table 13 shows that the drip irrigation system is a newly developed phenomenon as a majority of the farmers adopted this system recently. This shows the declining trend of water table (water scarcity) brings the issue of negative externality into the forefront of resource economics debate.

Table 13: Distribution of Farmers by Adoption of Drip Irrigation

Area	1993	1994	1997	1998	2000	2002	2003	2004	2005	2006	Total
LWIA	0 [0.0] (0.0)	1 [3.2] (100)	2 [6.5] (66.7)	1 [3.2] (20.0)	1 [3.2] (100)	3 [9.7] (60.0)	7 [22.6] (100)	6 [19.4] (75.0)	5 [16.1] (100)	5 [16.1] (83.3)	31 [100] (72.1)
HWIA	2 [16.7] (100)	0 [0.0] (0.0)	1 [8.3] (33.3)	4 [33.3] (80.0)	0 [0.0] (0.0)	2 [16.7] (40.0)	0 [0.0] (0.0)	2 [16.7] (25.0)	0 [0.0] (0.0)	1 [8.3] (16.7)	12 [100] (27.9)
Total	2 [4.7] (100)	1 [2.3] (100)	3 [7.0] (100)	5 [11.6] (100)	1 [2.3] (100)	5 [11.6] (100)	7 [16.3] (100)	8 [18.6] (100)	5 [11.6] (100)	6 [14.0] (100)	43 [100] (100)

Source: Primary survey

Note: Figures in parentheses indicate row and column-wise percentages to total, respectively.

Interestingly, in HWIA, a large majority of the small farmers have adopted drip irrigation as a coping mechanism though it is capital intensive (Table 14). This is an indication of resource exhaustion and way out for them to sustain agriculture. During our field visit, we learnt that a large majority of the farmers had adopted drip irrigation due to crop failure on account of water scarcity. It is a welcoming change that they had realized the importance of water saving technologies such as drip irrigation in resource conservation after the crop loss. A few small and marginal farmers had obtained subsidies to adopt drip irrigation method. Therefore, small and marginal farmers have also adopted drip irrigation method though it is capital intensive.

Table 14: Expenditure on Drip Irrigation by Farmers

Expenditure on drip irrigation (Rs.)	LWIA				HWIA			
	Marginal Farmers	Small Farmers	Medium Farmers	Large Farmers	Marginal Farmers	Small Farmers	Medium Farmers	Large Farmers
Less than 10000	0 (0.0)	4 (57.1)	3 (50.0)	5 (29.4)	0 (0.0)	1 (10.0)	0 (0.0)	0 (0.0)
10001 to 25000	1 (100)	2 (28.6)	1 (16.7)	3 (17.6)	1 (100)	1 (10.0)	0 (0.0)	0 (0.0)
25001 to 50000	0 (0.0)	1 (14.3)	2 (33.3)	3 (17.6)	0 (0.0)	2 (20.0)	0 (0.0)	1 (100)
More than 50000	0 (0.0)	0 (0.0)	0 (0.0)	6 (35.3)	0 (0.0)	6 (60.0)	0 (0.0)	0 (0.0)
Total no. of farmers	1	7	6	17	1	10	0	1

Source: Primary survey

Note: Figures in parentheses indicate percentage to total

In the LWIA, cropping pattern, and perennial plantation crop, allow them to adopt drip irrigation method. The farmers have been striving to give protective irrigation to the coconut plantation to alleviate the moisture stress to prevent drastic fall in the productivity. However, the farmers are not adopting drip irrigation in HWIA to the extent that is seen in the LWIA due to the following reasons: (a) drip irrigation is not amenable to cropping pattern in HWIA which is dominated by short term food crops; (b) farmers are not venturing into subsidy schemes for drip irrigation; (c) lack of awareness on the part of farmers to adopt such water saving methods; and (d) flow method of irrigation is required to prevent weed growth especially for paddy crop. All these are contributing for non adoption of drip irrigation on a large scale.

Changing Cropping Pattern

Nearly one-third of the respondents have adopted changing cropping pattern as coping strategy to overcome water scarcity problem in HWIA whereas this proportion was nearly one-fourth in LWIA. The changing cropping pattern was mainly due to inadequate water supply for the crops. The cropping pattern has been shifting from high water intensive crops to low water intensive crops such as coconut, ragi, groundnut and sunflower. The degree of shifting cropping pattern was high among small farmers as they were not able to cope up with severely declining water table. Importantly, the difference between LWIA and HWIA was clearly visible in the shift of cropping pattern. For instance, initially, paddy was the major water intensive crop both in HWIA and LWIA. With the increasing problem of water scarcity the cropping pattern was shifted from paddy to low water intensive plantation crops – coconut – in LWIA whereas ragi and groundnut as dominant dry land crops were adopted by farmers in HWIA. The rate at which the fallow land was increasing was also high in HWIA.

Thus, the overall scenario with respect to adoption of coping mechanisms revealed that a majority of farmers were actively involved in adopting coping strategies. The small farmers adopted less capital intensive coping mechanisms while large farmers adopted capital intensive measures. The results supported from the studies by Shyamsunder (1997) and Nagaraj and Chandrashekhar (n.d.) that farmers to cope with well failure go for change in cropping pattern in favour of less intensive crop, go for deepening of well and drill additional well. Further, the adoption of different conservation practices by different categories of farmers in the groundwater overexploited area supports the hypothesis that overexploitation of groundwater has differential impact on different categories of the farmers in terms of the conservation measures.

Conclusion

Overexploitation of groundwater resource is evident at different degree in the study area. The high degree of groundwater exploitation is a major threat to its sustainability and equity leading to inefficiency in the resource use pattern. The groundwater based agriculture can hardly sustain given the current rate of resource development in the study region. Added to this, groundwater resource status is also deteriorating leading to bankruptcy of the aquifers. The overexploitation of groundwater in the study area is largely because of institutional failure. The existing institutional arrangement only promoted overexploitation of aquifers and failed to generate adequate incentives for the adoption of efficient water use technologies. Thus, appropriate policy measures aimed at regulation and control of groundwater development is the need of the hour. Although watershed programmes implemented by the state and international agencies have promoted recharge capacity of the aquifers in several places, the rate of extraction is exceeding its recharge rate in the wake of increasing demand for groundwater.

The major institutional backup to exploit groundwater in Karnataka came with free power supply to irrigation pumpsets prior to 1997. The Government of Karnataka, however, imposed a flat charge of Rs. 300 per HP per year up to 10 HP pump set since April 1997 (Hemalatha and Chandrakanth 2003). Prior to April 1997, there were no explicit costs of irrigation as there were no operational costs of payments towards electricity utilization. This further continued with political support to provide free power supply for agricultural purpose which hastened the exploitation of aquifers beyond its natural recharge capacity. In addition, recently, free registration of electric pump sets has been introduced to have counts on mechanized pumpsets in the state. However, it is necessary to introduce pro rata tariff for electricity used for agriculture purpose to prevent overexploitation of the aquifers. Unfortunately, LWIA is also falling into the jar of overexploitation due to mining of aquifers in the wake of sustaining capital intensive cash crops.

The study clearly suggests the following for future policy actions:

1. inter well distance in relation to groundwater availability should be strictly maintained;
2. wherever cropping pattern is dominated by perennial plantation cash crops groundwater exploitation is minimum, which has dampened negative externalities of overexploitation to some extent. For instance, cultivation of low water intensive crops itself is a coping mechanism in LWIA. Therefore, there is scope to educate farmers to adopt light water crops;
3. traditional water bodies such as tanks and streams should be efficiently managed. Hence, groundwater recharge can be done while extracting required quantity of groundwater for sustaining crops. Therefore, care should be taken to integrate institutional and technical aspects of surface and groundwater sources that alleviate overdraft problem;
4. framers need to be educated to adopt water saving technologies to increase water use efficiency and to arrest overexploitation of aquifers;
5. the problem of inequity existing in well irrigation could possibly be addressed by promoting group investments in well irrigation where sharing the cost and benefits among the farmers are crucial. The group investment on well irrigation could probably solve the problem of over extraction of groundwater that would encourage the principle of *more crops per drop*; and
6. social regulation over groundwater use is necessary to counteract overexploitation which minimizes the pressure on groundwater resource. However, community participation is the primary prerequisite for the success of social regulation as it involves the group of people whose land is adjacent.

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Notes

[1] This agro-climatic zone, next to eastern dry zone in the state, is reported to have serious groundwater problems.

[2] The actual area irrigated is higher than the figure mentioned in the official record. Besides, the area irrigated by tanks and other sources was mentioned high in the official record. However, the general picture in the sample villages is far from reality where groundwater is the only source of irrigation due to drying up of tanks.

[3] Declining irrigation potentiality of surface water bodies is on account of two major factors in the study area, viz., human and nature intervention.

[4] Well density refers to the number of wells per unit area and the area per well is the reciprocal of the well density. While calculating the well density of the total land holdings of the entire sample farmers, the total number of all type of wells were considered (functioning and non-functioning).

[5] These are different forms of securities for human development in the world. Food security is said to exist when people have access to sufficient, safe, and nutritious food at all times to meet their dietary needs and food preferences to lead an active and healthy life (FAO, 1996a).

[6] Chandragiri - a village in Madhugiri taluk – has been bearing the brunt of well failure since 2003. The village was once a *arecanut and paddy granary*, now it has

become dry area due to water scarcity. Nearly 25 acres of areca plantations have gone dry in the village. Farmers who realized the problem adopted water saving methods such as drip irrigation method. However, by the time of adoption of such methods, the entire crop area had become dry. This created a lot of debate among farmers themselves about interlinking rivers to preserve water bodies such as tanks to facilitate aquifer recharge in the area. Unfortunately nothing has happened.

[7] A few farmers in Chandragiri village have been transferring water from the neighboring village since 2002 to protect arecanut plantations. Initially, a group of households came together and hired tractor to transfer water on daily rental basis. Later, they have discovered that it was not economical. They installed a pipeline for obtaining water. This coping mechanism was adopted by large farmers who could afford to invest on transferring water from far-off places. However, this mechanism could not sustain due to several reasons.

[8] The other sources of capital investment on well irrigation with a consequence, sale of assets such as livestock, trees (eg., eucalyptus, teak etc.) and land. Gold mortgage was also observed. Interestingly, the crop loan was used for the repayment of old loans by several small and marginal farmers.