Working Paper No. 174

Are wells a potential threat to farmers' wellbeing?
The case of deteriorating groundwater irrigation in Tamilnadu

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September 2002

ARE WELLS A POTENTIAL THREAT TO FARMERS' WELLBEING? THE CASE OF DETERIORATING GROUNDWATER IRRIGATION IN TAMILNADU*

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ABSTRACT

With the burgeoning population and fast industrial expansion, demand for water also goes up substantially. In order to meet the food grain requirements of the population there is an acute need for expanding the area under the irrigated agriculture. Since in many States, surface water sources have been utilized fully, there has been a massive expansion of the groundwater irrigation. With the progressive decline in the water table farmers have resorted to the competitive deepening of the wells. This has resulted in the increased costs of well irrigation and further has resulted in a new inequity among the well owners and between well-owning and non--well-owning farmers. Similarly, the urban water demands have increased tremendously for domestic and for industrial purposes. While there has been an ever-raising demand for water, hardly has there been any effort to develop the infrastructure to treat the used water. This is dangerous and contributes to the pollution of the existing water stock. Therefore, water resources are under severe threat not only because of the ever-increasing demand and competing demand (by various sectors) but also because of the diminishing quality caused due to the discharge of untreated domestic sewage and industrial effluent. In the coastal regions the problem gets compounded due to seawater intrusion. The main objective of this paper is to show how the degradation of the groundwater resource base through over-extraction and pollution contribute to inequity, conflicts, competition and above all to indebtedness and poverty.

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* This paper is the outcome of the larger study on 'Local Water Supply Options and Conservation Responses' carried out with the financial support of the International Development Research Center (IDRC), Canada. We gratefully acknowledge the research assistance provided by Dr.K.Sivasubramanian and Mr.G.Jothi. However, the authors alone are responsible for the views expressed in this paper.

ARE WELLS A POTENTIA THREAT TO FARMERS' WELLBEING? THE CAS OF DETERIORATING GROUNDWATER IRRIGATION IN TAMILNADU

Core Arguments

In this paper we argue that degradation of the groundwater resource base through over extraction and pollution are increasing rural poverty, social inequity and conflict in parts of India, particularly Tamil Nadu.

Groundwater is a crucial productive resource in both Tamil Nadu and India as a whole. For rural agricultural population it has almost replaced land as a determinant of social and economic status. Increasing groundwater access has undermined maintenance of tank irrigation systems and other surface sources. In the process it has shifted the determinants of water access away from communities and into the hands of individuals. While access to groundwater has never been fully equitable due to natural variability in resource conditions, landownership, wealth and other factors, inequity is growing. Patterns of inequity are socially embedded and exacerbated by factors such as inheritance patterns. In many cases, the ownership of individual wells is now divided among many people. This can be a source of conflict and often results in differential access between dominant owners and others who are less capable of exercising their partial ownership rights. Competition and conflict are increasing in the face of pollution and substantial water-level declines. Falling water levels are leading to competitive deepening and, in many areas, large financial losses as existing wells become dry or new, unproductive, wells are drilled. In many areas, shallow dug wells have gone dry and farmers now drill multiple bores alongside or within existing dug wells. Water level drops are also leading to the decline of surface sources, such as the traditional 'spring' channels used to divert the sub-surface flow in streams.

Water level declines and pollution are affecting the availability and reliability of water supplies for irrigation and other uses. Farmers have responded to scarcity by adopting efficient water use technologies. Nonetheless, water scarcity is reducing yields and having a direct impact on agricultural incomes. Indirect impacts are also major.

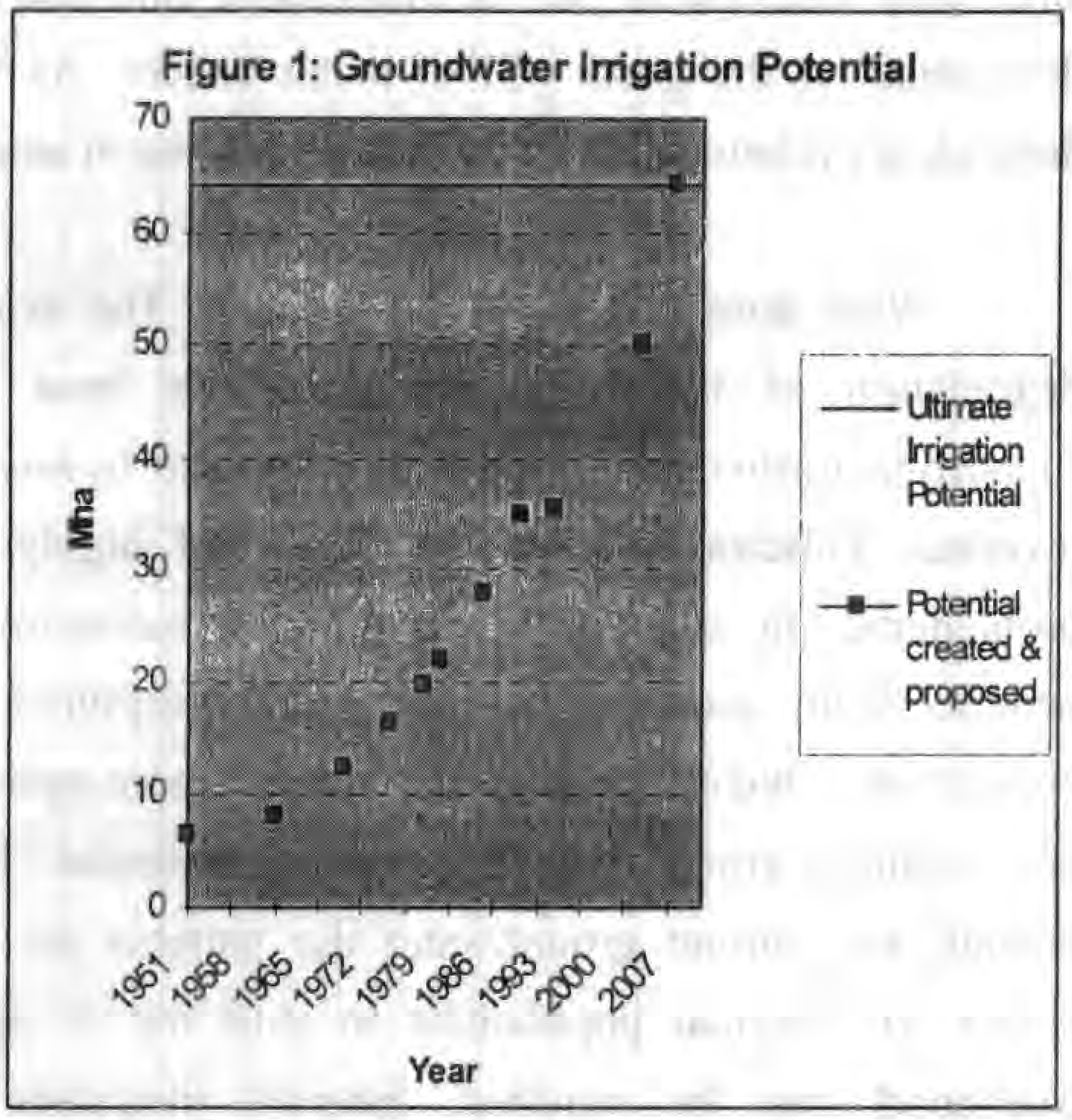
Informal markets, for example, initially emerged as farmers with access to surplus supplies sold water to adjacent farmers who either lacked the financial resources to dig their own wells or had insufficient supplies in the wells they did own. Now water markets are declining as farmers reserve all available supplies for their own use. Furthermore, even where water markets continue to exist, their operation is often highly inequitable since they function as part of interlocked land and labor markets where purchasers are dependent on the good will of water sellers. As water becomes increasingly scarce, dependency relations intensify with purchasers in an ever-weaker bargaining position.

What does this imply for policy? The evidence of increasing poverty due to degradation of the groundwater resource base implies that government policies supporting further groundwater development in areas suffering from overdraft must be reversed. Policies such as the supply of highly subsidized power are particularly problematic. In addition to encouraging indiscriminate and wholesale pumping, the benefits from such policies are largely captured by wealthy sections of the rural population. Overall, policies that support more equitable access to – and sustainable use of – available groundwater resources are essential. Furthermore, in areas where inequity is high and current groundwater use patterns are unsustainable, policies support the efforts of marginal populations to shift out of agriculture and into other forms of livelihood may be required. Inherent inequities in power relations within rural communities imply that 'simple' legal or other reforms to directly address groundwater overdraft and pollution are likely to be insufficient.

Organization of the paper

This paper is organized in the following manner. The first introductory section presents an overview of the growth of groundwater irrigation in India and highlights some of the problems emerging in many regions. Following this, the focus shifts to a detailed case study of the situation in Tamil Nadu where conditions illustrate the challenges emerging in the two-thirds of India underlain by hard rock aquifers. The first major section in the Tamil Nadu case study focuses on the characteristics of groundwater irrigation and use in the Vaigai, Noyyal and Palar basins. We then move to the core issue of water level declines the dynamic process of competitive deepening. The costs of well irrigation and its relationship with the costs of surface irrigation are discussed following this along with analysis of how well irrigation is accelerating the process of social differentiation within village society. The final section summarizes conclusions at both the local and all India levels and discusses possible policy options.

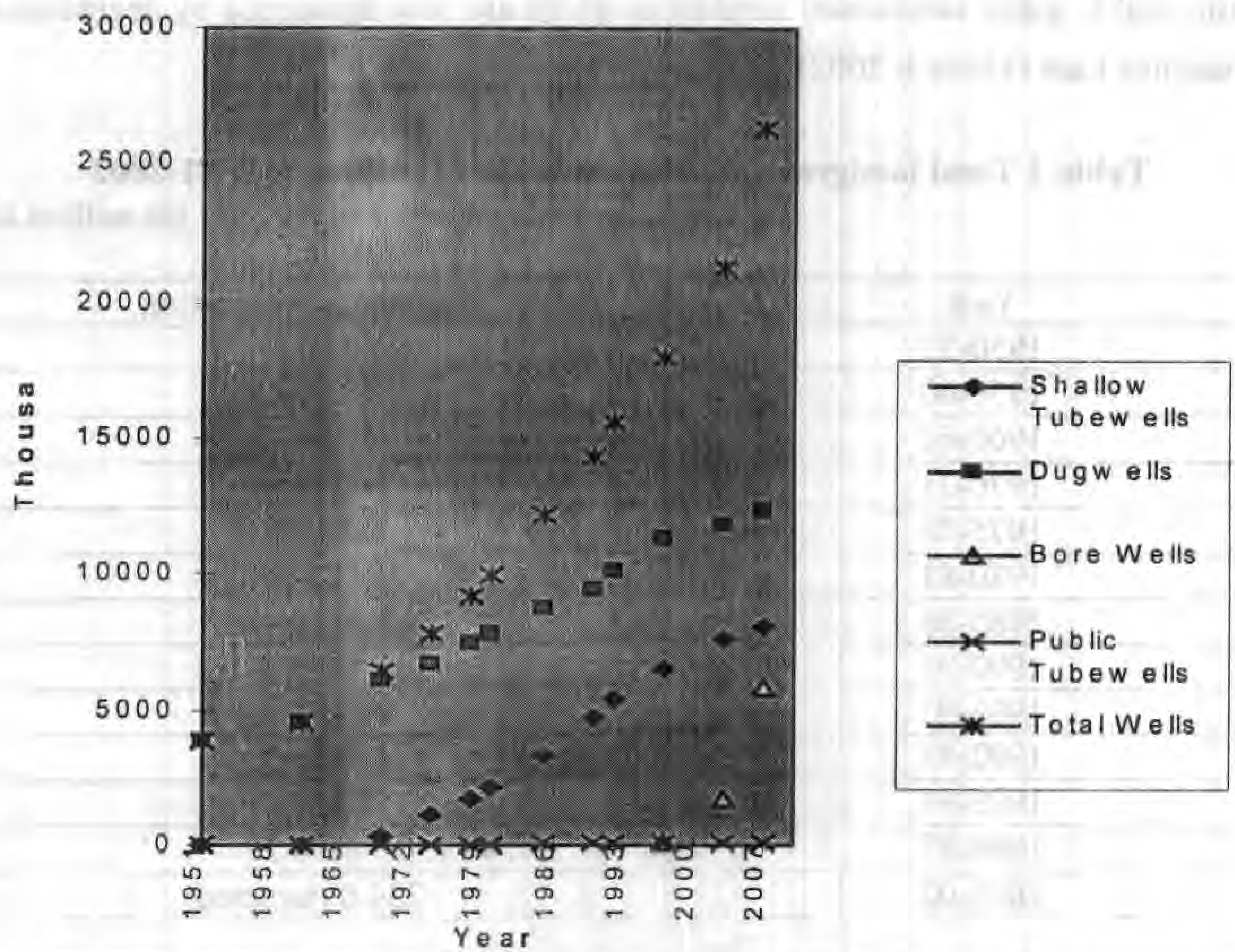
Section 1: Introduction



In the decades since independence, official statistics indicate that the number of wells and area irrigated by groundwater in India have grown and are projected to continue growing at an exponential pace until the 'ultimate' irrigation potential is reached circa 2007 – Figures-1 and 2 (Moench 1992; Moench 1992; World Bank 1998). This increase in groundwater irrigation has been a major factor contributing to the increase in yields and agricultural production at an all India level. Yields in groundwater irrigated areas are higher by one third to one half those in areas irrigated from surface sources (Dhawan 1995). The variability of production has also declined, in large part thanks due to the reliability of groundwater sources (World Bank 1998).

From approximately 50 million tons in the early 1950s, India's cereal production has increased steadily to a level of 234 million tons in 2001-2 (see Table-1). Per capita availability of food grains also have gone up steadily over a period time from 141 kilograms per year in 1951 to 200 kilograms in the year 2000. Rice and other cereals are now exported. Nevertheless, production has not resulted in food availability for all sections of society. While there is a strong association between levels of groundwater development and reductions in poverty, inequity remains and progress is threatened by

Figure 2: Growth of Well Numbers in India



emerging overdraft and other groundwater problems (Moench 2001; Moench 2002). While India has been able to create and maintain a large buffer stock of food grains, a variety of concerns are emerging both at a global level and within India. According to Rosegrant at a global level: "the growth rate in irrigated area declined from 2.16% per year during 1967-82 to 1.46% in 1982-93. The decline was slower in developing countries, from 2.04% to 1.71% annually during the same periods." (Rosegrant and Ringler, 1999). Yield increase rates are also declining and projections indicate that this will continue over coming decades (Rosegrant and Ringler 1999; FAO 2000). Furthermore, in some local areas such as Sri Lanka and in the rice-wheat system of India, Nepal, Pakistan and Bangladesh, yields have been stagnant for a number of years (Amarasinghe, Mutuwatta et al. 1999; Ladha, Fischer et al. 2000). Much of this may be related to emerging groundwater problems, particularly overdraft and pollution. We do not, however, believe that the relation is a simple one. Instead, the impact on yields and agricultural production – and more importantly, the impact on rural livelihoods – is by unsustainable development and power relations at a village level. As one of the authors argues elsewhere, over recent decades groundwater has played a crucial role in creating stable social conditions, conditions which are now threatened by degradation of the resource base (Moench 2002).

Table-1 Total foodgrain production in India 1959-60 to 2001-2002

(in million tons)

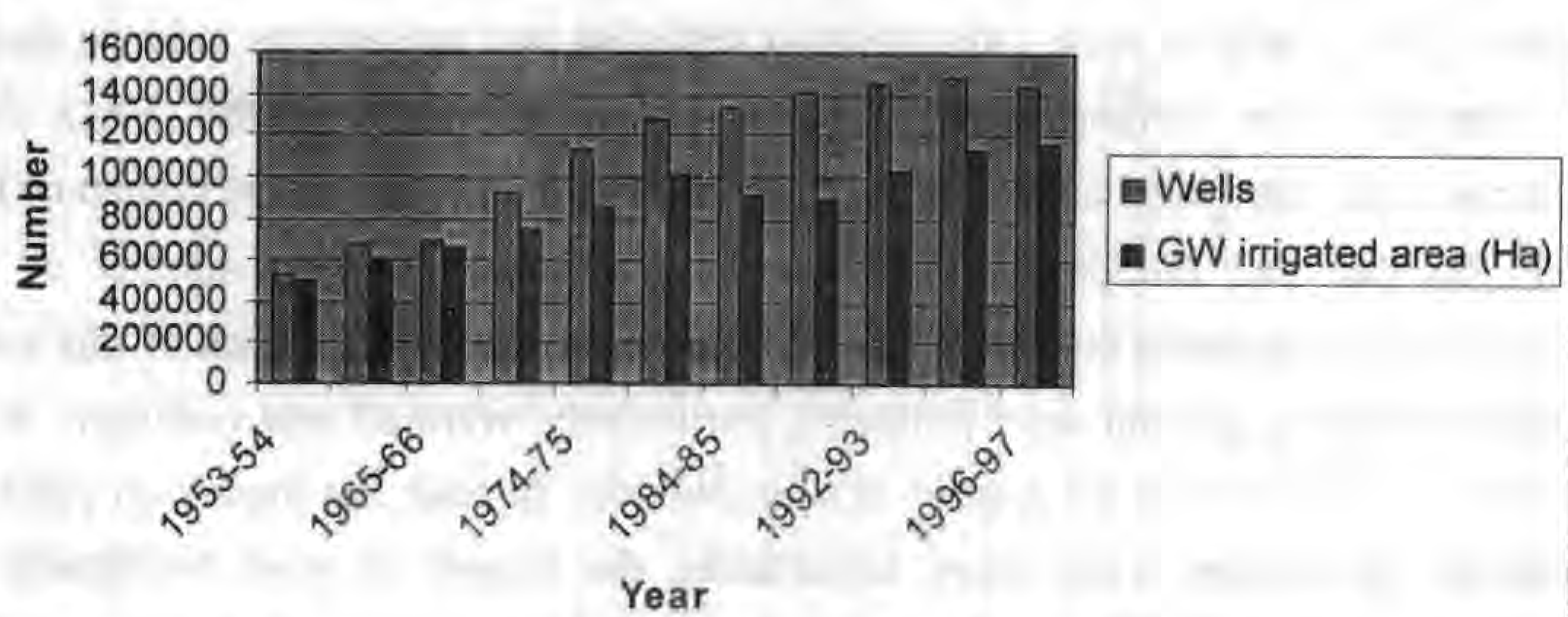
Year	Foodgrain production
1950-51	50.8
1959-60	74.7
1960-61	79.3
1970-71	108.4
1975-76	121.0
1980-81	129.6
1985-86	150.4
1990-91	176.4
1991-92	168.4
1992-93	179.5
1993-94	182.1
1996-97	199.3
2001-02	234.0 (targeted)

Source: Center for Monitoring Indian Economy: Agriculture, November 2000.

The situation in Tamil Nadu illustrates many of the issues that are now emerging in many hard-rock sections of India. Increasing well numbers are not, as Figure 3 demonstrates, equivalent to an increase in groundwater irrigated area.

Figure 3: Well Irrigation in Tamil Nadu

Source: Season & Crop Reports, Govt. of TN



Well numbers in Tamil Nadu are following a logistic pattern with the exponential growth rates of the 1950s through 1980s now slowing or even declining. Furthermore, although well numbers have been increasing, groundwater irrigated area has stagnated since the early 1980s. This pattern has emerged despite the presence of an extensive system of subsidies encouraging continued expansion of groundwater development.

What are these subsidies? The most important of them has been the provision of free power to agricultural pump sets. This cost the exchequer approximately Rs.20 billion in the year 1999. Other subsidy schemes have included the provision of low interest loans for deepening existing or constructing new wells, for purchasing pumps and for other equipment. The power subsidy has encouraged high levels of groundwater pumping and is widely implicated as a contributing factor in emerging groundwater overdraft problems (Malik 1993; Moench 1993; World Bank 1998). Well development subsidies have also had a significant impact. Despite the presence of well spacing regulations, a study undertaken in the Vaigai basin of Tamilnadu, indicates that there are now at least three wells located within the prohibited distance from every sample well selected for the survey (Janakarajan, 1997a). Furthermore, while subsidy schemes have encouraged groundwater development, very little attention has been devoted to the maintenance of traditional irrigation sources such as tanks and 'spring' channels[1]. See Table-2 which provides data on trends in the net irrigated area by sources in India. This table explains the fact that while wells irrigation has increased by many folds, area irrigated by the conventional sources such as tanks is on the decline.

Table-2 Trends in Net Irrigated Area (NIA) by sources in India, 1950-51 1996-97

(Area in million hectares)

Sources	1950-51 to 59-60		1960-61 to 69-70		1980-81 to 89-90		1996-97	
	Area	% of NIA	Area	% of NIA	Area	% of NIA	Area	% of NIA
Canals	9.2	41.2	11.2	41.9	16.3	38.3	17.4	31.5
Tanks	4.2	18.6	4.5	16.6	3.0	7.0	3.3	6.1
Wells	6.6	29.8	8.7	32.6	20.8	48.7	30.8	55.9
Other sources	2.3	10.4	2.4	8.9	2.5	6.0	3.6	6.6
Total NIA	22.3	100.0	26.8	100	42.6	100	55.1	100

Source: Indian Agricultural Statistics, 1985-86 – 1989-90, Vol.I, Ministry of agriculture, Government of India and quoted in Vaidyanathan (ed.) 2001, and CMIE, September 1998

[1] 'Spring' channels are traditional methods for diverting the sub-surface flows.

These sources have played a key role not only in providing irrigation water for several centuries, but also in recharging groundwater and, thereby preserving local environmental systems. Now many tanks and spring channel sources have dried up, become clogged with silt or been encroached on for construction or cultivation. Finally, in some other parts of the State (such as in the Palar basin), channels are being used to drain industrial effluent. This is occurring despite the presence of pollution abatement laws. Overall, while substantial attention has been devoted to promoting groundwater irrigation, inadequate or no attention has been paid to effective avenues for sustaining the resource base or for the impact of emerging depletion and pollution problems on rural society.

Groundwater is a crucial productive resource. Our research in Tamil Nadu indicates that access to it has almost replaced land in determining one's socio-economic and political status (Janakarajan, 1992, 1997a). In the past, when surface water was the only source of irrigation, the single most important productive resource was land. At that time, access to land determined one's power as well as socio-economic status in a village society. The rapid growth of groundwater irrigation, change in cropping patterns from drought tolerant – but relatively low yield – varieties to higher-yielding but water sensitive varieties, and declining status of traditional surface sources have resulted in emergence of groundwater as a crucial productive resource. Therefore, in a changing agrarian context, it is the ownership of wells along with land, which determines one's status. In Tamil Nadu, marginal and small farmers own 60% of the wells (Janakarajan, 1997a). Ownership of wells is, however, nothing unless they are productive and can be maintained. As a result, ownership of 60% of wells by small and marginal farmers does not mean greater access to groundwater resources. Declining water levels create a situation in which only those who are able to afford to compete in a process of competitive deepening can maintain access. Growing inequity in access to groundwater leads to a process of continued social differentiation, which results in deprivation, poverty and the consolidation of inequitable power relations within local communities. In the sections that follow these topics are the focuses for detailed analysis based on field data collected in Tamil Nadu.

Section 2: Groundwater Ownership and Access in Tamil Nadu

Groundwater access depends on a wide variety of factors but one of the most important is the question of well ownership and the ways those interact with social relations and power structures in a village context. Groundwater access rights are fundamentally different from rights in traditional community managed or State managed surface irrigation systems. Under British Common Law, the basic civil law doctrine governing property ownership in most of India, groundwater rights are appurtenant to land (Singh 1990; Singh 1991). If you own land, you can drill or dig a well and capture as much groundwater as you are able for use on overlying lands. When land is sold, groundwater access rights pass with the land and cannot legally be separated from it. Formal legal definitions of rights, however, are often quite different from the practical 'rules in use' that determine the effective access any individual may or may not have to groundwater. In Tamil Nadu, some of the most important factors affecting access to groundwater include whether wells are owned by individuals or held jointly and ownership of wells across different categories of landowners. These ownership factors are affected by well density, area irrigated by wells in relation to area irrigated by surface sources; crop pattern and yield performance.

2.1 Ownership of wells

2.1.1 Sole and Joint ownership of wells

In Tamil Nadu, agricultural land is generally divided between heirs at the time of inheritance. Increasingly this is also the case with wells. Because landholdings are relatively small, water is a critical resource and wells are key productive assets, ownership of wells is often split into shares at the time of inheritance. As a result, wells in Tamil Nadu are increasingly shifting from single owners to joint ownership. This is of fundamental importance for understanding emerging groundwater problems and potential solutions because it has become a central point of conflict within communities and families. Joint ownership is increasing the rate of differentiation between the "haves" and "have-nots." Sometimes the results are extreme; after inheriting a share in a well individuals often deepen their own portion and effectively exclude other shareholders from access to water. These types of micro-level conflicts complicate decision making and appear to be undermining the possibilities for consensus for sustainable use of the resource base.

Incidence of Joint Well Ownership

The association of groundwater ownership with land ownership in combination with inheritance laws has encouraged sub-division and fragmentation of wells into many shares along with land. As opposed to sole ownership of wells, virtually there is no macro-database documenting the nature and extent of joint well ownership. Village level studies conducted in various river basins in Tamilnadu by the first author, however, indicate the widespread nature of joint ownership and highlight dilemmas and uncertainties associated with management of jointly owned wells.

Joint ownership of wells is common in Tamil Nadu. Data collected in a survey of 1100 wells in 27 villages of the Vaigai river basin (in southern Tamilnadu) indicate that on an average, about one-third of the wells are jointly owned in that area (Janakarajan, 1997a). Higher levels of joint ownership (47 percent of the sample) were found in another survey of 11 villages in the Palar river basin (Janakarajan, 1999). Research conducted in the Noyyal and Palar river basins for the *Local Water Management Project* also shows a high incidence of joint well ownership (see Tables 3 and 4). Of, 7120 sample wells in 51 villages covered by the meso-level survey in the Palar basin, the overall percentage of jointly owned wells is 43.6 %. The extent of joint ownership is not, however, uniform between villages. At the village level, joint ownership varies from 17.2% to 59.1%. Variation is even higher in the Noyyal basin. Of 14358 surveyed in 41 villages, 53% are jointly owned and at the village level joint well ownership varies from 31.3% to 87%. Joint ownership of wells is a complicated phenomenon with the number of shares in any individual well varying from a minimum of 2 to as many as 30 in the Palar and Noyyal basins (see Tables 3). There is some indication that jointly owned wells are more likely than individually owned wells to be in disuse. For the Palar basin as a whole the percentage of joint wells in disuse is 30.4%, whereas, it is only 24.7% in the case of individually owned wells. This pattern is, however, not prevalent in the majority of villages in either the Palar or Noyyal basins.

Table 3: Well Ownership Patterns in Palar and Noyyal Basins, 1998-99

Cluster Number	Villages in each cluster	Number of wells	Individually owned wells	Jointly owned wells	Individually owned wells %	Jointly owned wells %	Maximum number of shares in wells
PCluster-1	2	499	302	197	60.6	39.4	9
PCluster-2	21	2803	1779	1024	63.5	36.5	29
PCluster-3	5	476	270	206	56.7	43.3	10
PCluster-4	8	1666	681	985	40.9	59.1	8
PCluster-5	13	1006	427	579	42.4	57.6	8
PCluster-6	2	670	555	115	82.8	17.2	5
All Clusters in Palar	51	7120	4014	3106	56.4	43.6	-
NCluster-1	4	1819	1250	569	68.7	31.3	10
NCluster-2	5	1225	781	444	63.8	36.2	9
NCluster-3	2	438	57	381	13	87	15
NCluster-4	2	510	190	320	37.3	62.7	15
NCluster-5	7	4610	2112	2498	45.8	54.2	9
NCluster-6	4	1670	325	1345	19.5	80.5	5
NCluster-7	6	1841	854	987	46.4	53.6	30
NCluster-8	6	634	335	299	52.8	47.2	11
NCluster-9	5	1611	829	782	51.5	48.5	20
All clusters in Noyyal	41	14358	6733	7625	46.9	53.1	

PCluster-1: Upper reach of the Palar basin, no tannery effluent;
PCluster-2 Upper reach of the Palar basin where tanneries are concentrated;
PCluster-3 Upper reach of the Palar basin where tanneries are concentrated;
PCluster-4 Middle of the Palar basin where tanneries and industries are concentrated;
PCluster-5 Middle of the Palar basin where tanneries are concentrated;
PCluster-6 Middle of the basin where tanneries are not located.
NCluster -1 Villages in Noyyal basin along the Tiruppur - Avinashi road;
NCluster -2 : Villages in Noyyal basin along the Tiruppur - Perumanallur road;
NCluster -3 : Villages in Noyyal basin along the Tiruppur -Uthukuli road;
NCluster -4 : Villages in Noyyal basin along the Tiruppur - Kangayam road;
NCluster -5 : Villages in Noyyal basin along the Tiruppur - Dharapuram road;
NCluster -6 : Villages in Noyyal basin along the Tiruppur - Palladam road;
NCluster -7: Villages in Noyyal basin along the Tiruppur - Mangalam road;
NCluster -8: Villages in Noyyal basin along the Tiruppur - Orathapalayam road;
NCluster -9 Villages in Noyyal basin around Chennimalai textile units.

Source: Meso-level survey, 1997-98

Share ownership of wells across different size categories of farmers

In addition to the widespread extent of shared well ownership, data from eight sample villages in the Palar basin indicates that the size of shares is strongly associated with the extent of land owned by an individual farmer (see Table 4).

Table-4 Share ownership of wells in the Palar basin

Land holding (Acres)	No.of HHs reporting	Percent ownership in shared wells							
		<0.1	0.1-0.2	0.21-0.30	0.31 - 0.50	0.51-0.75	0.76 - 0.99	1 and more	Total number of wells owned in the size class
Upto 1.0	89	15	25	15	23	0	0	14	31.7
1.01-2.0	124	1	16	17	58	1	0	39	67.8
2.01-4.0	92	7	3	7	35	2	0	53	72.3
4.01-6.0	40	0	2	7	7	1	0	35	41.1
6.01-10.0	37	0	0	5	10	1	1	29	36.4
10.0-15.0	16	0	0	0	3	0	0	19	20.5
+ 15.0	8	0	0	1	0	1	0	12	1.3

Source: Main survey, 1998-00

Data in Table-4 highlight the skewed distribution of well ownership and the strong association with landownership. Key points to be noted include:

- That the average number of wells owned in each size class increases at an increasing rate as size class increases. This implies that better access to land is associated with the better access to groundwater.

- There is a negative association between extent of land ownership and the incidence of joint well ownership. Larger landowners tend to own wells outright rather than shares in wells. This could indicate either that they construct their own new wells or that they consolidate their shares in wells by purchasing from other shareholders.

- Unlike larger landowners, small landowners frequently own relatively small shares in wells. All sample farmers owning less than 20% shares in wells are concentrated in landownership classes having less than six acres of land. This suggests that small landowners are likely to be more vulnerable than others to losing access to groundwater.

In principle, share ownership of wells should enable sections of society who are unable to afford construction of their own well to obtain access to groundwater. Operation of shared wells is, however, often complicated by caste and other social factors. While we have not documented the details of the management of jointly owned wells for every case in the survey villages, our interviews suggest that the incidence of conflict in the process of sharing of water from jointly owned wells is widespread and that practical difficulties surrounding pumping and management of shares are the most important source of conflict. The nature and consequences of conflict are rooted in the nature and operational practices associated with joint wells.

Joint wells are commonly operated by installing a single pump set and running the motor in rotation between shareholders for a fixed number of hours. Operational costs are divided among shareholders in proportion to number of shares they own. Lack of cooperation in sharing costs and the available water / power supply are common problems. Unlike the disintegration of the traditional tank irrigation communities (which is primarily due to lack of incentives for management (Janakarajan, 1993)), financial constraints are the most common problem in the installation and operation of jointly owned wells. In cases where shareholders don't cover their portion of the costs, they are excluded from use of the pump set. Many disputes also occur due to the erratic power supply, which disrupts schedules for sharing available pumping time. Village Panchayats (informal village courts) are often involved in resolving such disputes but settlements are often not sustainable and emerge again in the next period of scarcity.

An alternative to sharing ownership and use of one pump on a joint well is for each shareholder to install their own individual electric or diesel operated pump set. This is possible because most wells are large diameter dug structures where the installation of multiple pumps is possible. This approach often leads to competition over available supply. Stored water is drained rapidly and competition is inflamed when shareholders install high-powered motors so that they can extract water rapidly. Disputes are particularly common when wells are shared by different castes. Such disputes are often only resolved when one shareholder buys the others out. In some instances this is accomplished by poor farmers selling their land along with their shares in a well.

In addition to disputes over pumping, disputes often occur over the need to deepen wells. In some of the cases we have documented, shareholders with different landholdings disagree regarding the distribution of the benefits from well deepening and one or more refuses to contribute to the cost. Conflicts under circumstances are again referred to the Village Panchayats. The Panchayats often 'solve' such disputes by dividing wells physically into as many shares as needed – leaving it thereby to the individual shareholders to dig and deepen their delineated parts. Such physically fragmented wells are common in all the villages surveyed. Although this approach is common, it often encourages competitive deepening between shareholders within wells – effectively the construction of wells within wells. In such cases, shareholders lacking the resources to deepen their own portion lose access to groundwater and the well is effectively controlled by those that remain. There are also instances where wells are abandoned due to the prevalence of too many shareholders and the emergence of numerous disputes.

The history of each joint well covered in the Palar basin was recorded as part of our survey. Initially, most wells were individually owned. Division into shares occurred subsequently, due primarily to the operation of inheritance laws. When land is divided among legal-heirs, wells are also divided. Therefore, most shareholders in joint wells are brothers or close cousins. Over time, however, shares are often sold to others for many socio-economic reasons. In a few cases, sole well owners have approached neighbors to share the cost of well deepening and effectively sold a share in their wells.

While sharing of water from a joint well is often problematic, positive features also exist. The fact that at least one-third of wells in our survey areas are jointly owned indicates the sustainability of this system. Indeed, in all the villages, there are institutionalized (informal) rules governing sharing of water from jointly owned wells. The joint well system promotes use of groundwater and particularly benefits those who cannot afford a well of their own. Many joint wells however, fail for two interrelated reasons; declining groundwater levels and the lack of finances for well deepening. Because of this many joint well owners became heavily indebted and are eventually forced to sell their shares along with their parcels of land. While the share system promotes equity in access to groundwater, inequality is again reinforced in village societies.

2.1.2 Ownership of wells across size categories of farmers

Because the development of a well for irrigation requires substantial investment, it is often portrayed as only affordable by the resource rich farmers. Our data does not support this. Survey data from 27 villages in the Vaigai basin indicate that nearly three-fourths of wells are owned by farmers owning 5 acres or less (Janakarajan, 1997a). A similar survey of 8 villages of the Palar basin indicates that the 65% of farmers whose holding size is less than or equal to 4 acres owns 54% of all wells. This group owns only 29% of the total land held by surveyed farmers. The average area irrigated per well is 1.46 acres in this size class. In contrast, the 3% of farmers owning more than 15 acres also own 8% of the sample wells and 19% of the total land. The average area irrigated by per well in this size class is 26 acres. More detailed data are given below in Table 5 and Figures 4 and 5. These data indicate that, while the wealthy do tend to own more wells, the distribution is far less skewed than land ownership. Average well ownership per unit land, in fact, declines exponentially as land ownership size classification increases. The data do not, however, indicate the type and productivity of the wells owned by different classes of farmers. Since the average area irrigated per well is far larger in the larger landholding classes, the wells may be more productive and actual access to groundwater may be more skewed than suggested by comparisons between well and land ownership alone.

Table 5: Ownership of wells across size classes of landholding in the Palar basin

Landholding size (in acres)	Number of well owners	Total number of wells owned	Total extent of land owned / irrigated (acres)	Average extent irrigated per well (acres)
Less than 1.00	26	29	16.7	0.64
1.01-2.00	64	86	101.7	1.59
2.01-4.00	67	100	193.9	2.89
4.01-6.00	28	43	140.8	5.03
6.01-10.00	35	75	257.7	7.36
10.01-15.00	14	35	173.8	12.42
15.01-25.00	5	13	97.0	19.40
25.00+	3	17	111.1	37.04
Total	242	398	1092.7	4.52

Source: Main survey, 1998-00

Figure 4: Well and Land Ownership in the Palar Basin

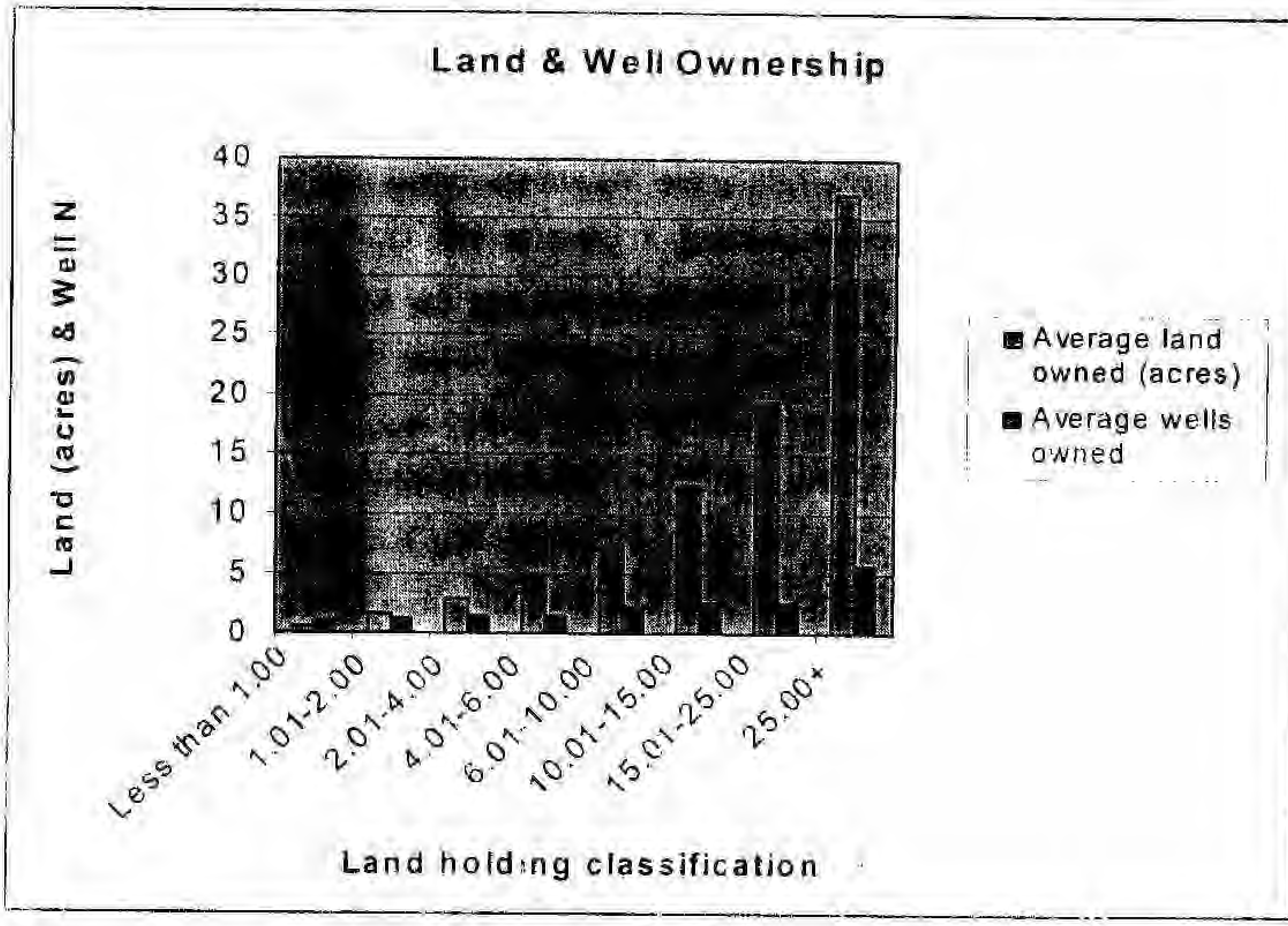
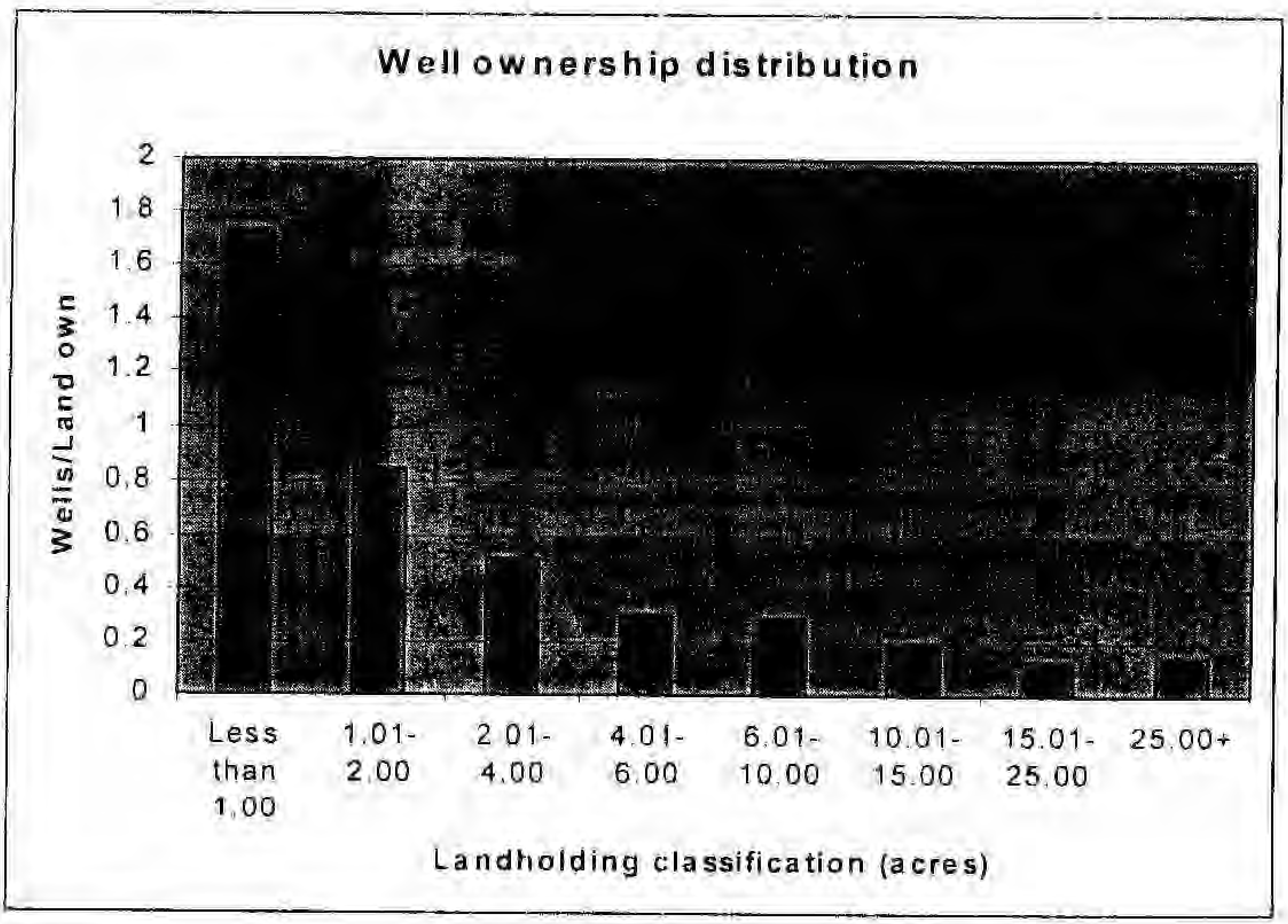


Figure 5: Average number of wells owned per unit land in Palar Basin



Although the above data indicate that well ownership is far less skewed than land ownership, a number of factors suggest that the poor may not be deriving as much benefit as it appears.

- First, as the data in Table 5 on area irrigated per well indicate, wells owned by larger farmers are likely to be much more productive and capable of irrigating large areas than wells owned by farmers in the smaller land holding classifications.
- Second, as water levels decline, large farmers are able to devote more resources to increasing the depth of their wells. In addition, access to larger land areas is equivalent to access to a wider variety of potential sites for establishing a well. Because hard-rock geology is highly variable, access to a variety of locations for new wells is often critical to success.
- Third, many of the more wealthy farmers established wells earlier than smaller farmers and were able to benefit from them before competitive deepening became a major issue. As a result, although the poor appear to own large numbers of wells, many are trapped in a regime in which water table is retreating progressively. Their position is quite vulnerable. In order to be able to remain in the race of competitive deepening, they have to keep investing in well deepening activities without any assurance of striking substantial quantities of groundwater. While some are successful, the large majority fail and are pushed into a debt trap. We shall get back to this issue in a later section.

2.2 Linkage between surface and groundwater

Extensive development of groundwater resources is affecting surface systems in the Palar basin. The Palar basin is known for its rich river bed aquifer (RBA). This contributes substantially to the 'spring' channels and, although extraction is prohibited, to thousands of wells located along the riverbed. Pumping of groundwater in the prohibited areas is drying up surface water bodies and results in the reduced flows down stream. Over 100 mld of water is pumped from the Palar riverbed for drinking and industrial purposes. Although the extent pumped for industrial and domestic purposes is small compared to what is pumped for agriculture, it has adverse effect for two reasons: One, what is pumped for domestic and industrial purposes is a potable quality, which is not available in all the villages. and two, such extraction of groundwater takes place in some selected regions or villages, causing tremendous stress on the local economy. Furthermore, this is having a direct impact on traditional 'spring' channels, which were originally constructed to tap subsurface flows in the river. These spring channels traditionally provided irrigation for at least one full crop. Historically, at least one such spring channel provided water for each village located along the riverside. Thousands of such spring channels are reported to have existed in Tamilnadu as per the village records. Most of these have now dried up and are encroached upon. Out of 51 villages surveyed in the Palar basin, spring channels are practically defunct in thirty five, they function but only poorly in six, and are fairly effective in three. In the remaining villages, spring channels have been taken over by the tanneries for discharging industrial effluent. Since these channels pass through interior parts of villages, even groundwater is heavily polluted.

In addition to the impact on river-bed aquifers, unregulated pumping of groundwater in tank commands is having a major impact. Since the number of wells located in tank commands is significant the tank is losing its place as an important source of irrigation. (Vaidyanathan and Janakarajan, 1989). The rapid spread of well irrigation, accompanied by large scale rural electrification and the introduction of high yielding technology, have contributed in a great measure to the rise of conflicting interests in the use of ground and surface waters. Since high yielding varieties required more assured, controlled and timely application of water and since the available tank water is inadequate to raise three short duration - HYV - crops, wells have major advantages over surface sources. Furthermore, some studies indicate a positive correlation between the rapid growth of well irrigation and the decay of traditional irrigation systems such as tanks (Vaidyanathan and Janakarajan, 1989, Janakarajan, 1993, Palanisamy, Balasubramanian and Mohamed Ali, 1996). Lindberg (1996) in his paper shows, how an individual rationality conflicts with collective rationality and eventually results in the erosion of common property resources. Individuals have strong incentives to disassociate themselves from collective tank maintenance and pump groundwater indiscriminately. This results in progressive lowering of the water table. The government's policy of supplying free electricity to agriculture has aggravated this problem. This leads to general environmental degradation where groundwater extraction is high and aquifer recharge declines due to the drying up of the surface water bodies such as tanks.

In our survey, traditional irrigation institutions were found to be defunct in 6 out of the 17 tanks studied in the Palar Anicut System. These were also the tank commands in which well density was quite high. In one of the tanks, the tank sluices were kept closed permanently to facilitate recharge into the wells located in the tank commands. In the rest of the operational tanks, the traditional irrigation system was reasonably unimpaired but these were also the tank commands in which the well density was very low (Vaidyanathan and Janakarajan, 1989, Janakarajan, 1993). A similar result was obtained in a large scale study, undertaken in Tamilnadu Agricultural University (Palanisamy, Balasubramanian and Mohamed Ali, 1996). The close association between a high well density and the disintegration tank irrigation systems has also been found in other village studies carried out in Tamilnadu (Harriss, 1982, Janakarajan, 1986, Chinnappa, B.Nanjamma, 1977, Janakarajan, 1997b). The result is, however, not uniform. A separate study of tanks in the Periyar-Vaigai system shows that the spread of well irrigation in the tank commands does not lead to a total collapse of the tank institution although its degree of effectiveness varies according to well density (Vaidyanathan and Sivasubramaniyan, 1998).

Our recent survey in 51 villages of the Palar basin indicates that there exists a close association between well density in the command area of tanks and springs and the decline of these traditional sources. In the villages surveyed, well density ranged from a low of 0.30 to a high of 0.79 per hectare; densities in wet lands - those traditionally irrigated from surface sources - are typically higher (0.33 to 0.79 wells per hectare) than those in dry lands (0.30 to 0.62 wells per hectare). This density was much higher than expected even in villages where tank irrigation institutions are reported to remain alive. According to interviews with farmers, the dependability of tank water is low and the risk and uncertainty associated with relying on it high. As a result, many farmers have invested in wells to get access to more assured irrigation. The tanks, if they function at all, are used as percolation ponds in most of these villages. Indeed, access to private source of irrigation (wells) has provided generous disincentive to farmers for non-cooperation in the collective action of tank and spring channel maintenance.

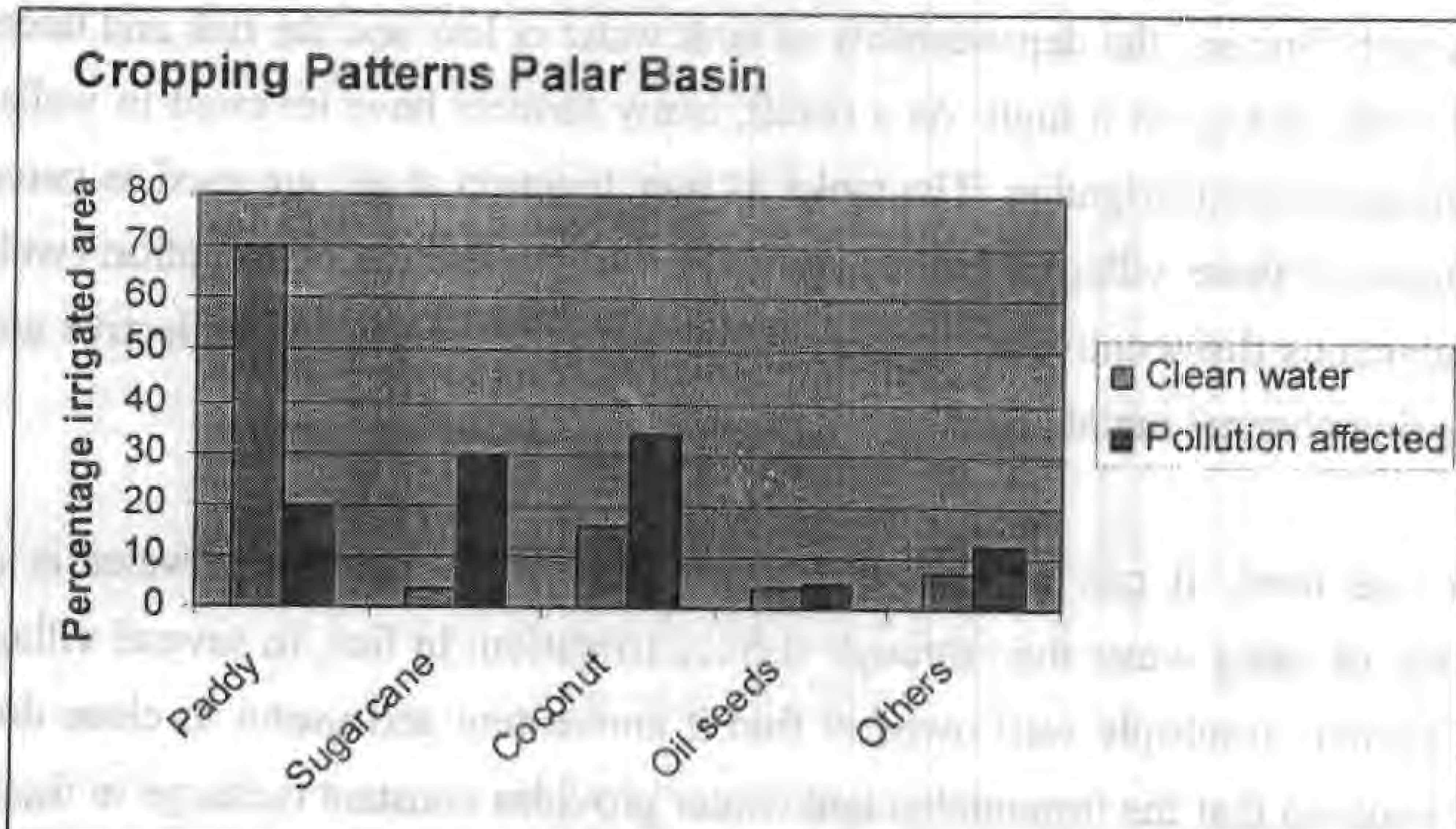
At one level, it can be argued that pumping recharged groundwater is a more efficient way of using water than through surface irrigation. In fact, in several villages, the better off farmers (multiple well owners) find it convenient and useful to close down the sluices of tanks so that the impounded tank water provides constant recharge to their wells. But, in many cases, since there is absolutely no maintenance of inlet channels, tanks and springs are heavily silted and store very little water. This has major implications for non-well owners who were solely dependent upon tank water.

Section 3 Pollution, Cropping Pattern and Yield

The Palar and Noyyal river basins are under severe stress not only due to over-use of groundwater but also due to pollution. It is, as a result, necessary to analyze irrigated areas, crop patterns and crop yields in this context.

In the main survey of the Palar and Noyyal basins, the net irrigated area per well in villages where groundwater has been affected by pollution is 2.72 acres; the average net irrigated area of 4.16 acres was found in the areas where groundwater has not been affected by pollution. Differences in cropping patterns are even more striking. The total area for all crops grown on land irrigated by sample wells in villages surveyed in the Palar basin is 903 acres, of this 505 acres (56%) is devoted to paddy. Over 90% (456 out of 595 acres) of this paddy is grown in villages where groundwater has not been affected by pollution. This is equivalent to 2.9 acres of irrigated paddy per sample well in the unaffected villages and only 0.50 acres of irrigated paddy per sample well in pollution affected villages. Cropping patterns in pollution-affected villages have larger areas devoted to sugarcane and coconut which tolerate reasonably the polluted water (See Figure 6). Distinctions in cropping patterns are not as great in the Noyyal basin because paddy is not a major crop.

Figure-6 Crop Pattern in the Palar Basin



The impact of over-use of groundwater and pollution on water scarcity is major in both the Palar and Noyyal basins. In about 33% (in 80 out of 253 sample wells) and 28% (80 out of 253) of the sample wells in the Palar and the Noyyal river basins respectively irrigated area is nil – implying the well is no longer utilized. The difference between affected and unaffected villages is substantial - 26% (41 out of 159 sample wells) in the unaffected and 41% (39 out of 94) in the affected villages of the Palar basin have zero irrigated area, and 25% in the unaffected (i.e., 28 out of 112 sample wells) and 34% in the affected villages (i.e., 23 out of 68 sample well) of the Noyyal river basin report zero area irrigated.

Differences in the net area irrigated by wells between affected and unaffected villages has a large impact on the crop yields. About one-third of the sample well farmers in both the river basins reported zero crop yield. Again the difference between affected and unaffected villages is substantial. While in the affected villages, 43% of the sample well farmers reported zero crop yield, only 28% do so in the unaffected villages. In both types of villages, however, the incidence of sample well farmers reporting zero yield is quite significant. In the case of villages where groundwater has not been polluted, zero yield is caused by groundwater over extraction and the drying up of wells. In villages affected by pollution, zero yields in sample wells are primarily due to severe water contamination. The economic impact of pollution are evident in the value of crop production in different villages. For instance, 79 out of 159

BOX 1: NOYYAL BASIN: VILLAGE: ORATHAPALAYAM; SAMPLE WELL CODE NO: OPM

This well owner has 5 wells and 18 acres of land. All the wells are inter-connected with pipelines. His original objective was to pump water from all the wells, channel them together for irrigation. This arrangement was done because the yield of water from his wells was low. The wells range from 50 to 70 feet in depth and the total amount spent in constructing them and installing five pumps, pump sheds, pipelines and other equipment came to Rs.13 lakhs (approximately $27,000 at Rs 48/$). The farmer profitbly engaged in agriculture until the late 1980s. In 1990 a dam was constructed in this village across the river Noyyal to irrigate 11000 acres. The sample well owner's destiny has changed since then. The dam collects all the effluent water discharged by 750 dyeing and bleaching units located in and around Tiruppur town. Because of very high TDS and other chemicals and salts contained in the water the stored water has never been used for irrigation. Unfortunately, however, all the wells belonging to the farmer were adjacent to the dam and became polluted. This farmer is at present growing coconuts, which tolerate salinity to some extent. His annual income has declined from about Rs.3 lakhs ($6250) to less than than Rs.50,000 ($1042). He has accumulated debts of Rs.4 lakhs ($8333). The condition of many small well-farmers is much worse; they have given up their cultivation in this village and have sought employment in the Tiruppur knit-wear and dyeing and bleaching industries.

sample wells (50%) in the unaffected villages of the Palar basin and 60 out of 112 sample wells (54%) in the Noyyal basin reported more than Rs.5000 value of crop yield per acre. In contrast; in the pollution-affected villages of the Palar basin only 16 out of 94 sample wells (17%) and 11 out of 68 sample wells (16%) in Noyyal reported more than Rs.5000 as the value of crop yields per acre. These impacts are particularly important for small farmers who cannot deepen wells or site wells in less polluted locations. As the accompanying box illustrates (see Box-1), however, the impact of pollution even on large farmers is often very substantial.

Section 4: Decline in the water table, Competitive deepening and its Socio-economic implications

In many parts of India, rapid expansion of groundwater irrigation has resulted in significant declines in groundwater levels and in some cases pumping rates exceed recharge resulting in groundwater mining (see for instance, Bhatia, 1992, Rao 1993, Moench 1992, Vaidyanathan 1996, Janakarajan 1997a). This is widely viewed as a major cause of competitive deepening and for the emergence of conflicting interests among well owners. Little data are, however, commonly available to document the extent to which water level declines have actually occurred in specific locations. The most recent formal statement on the status of groundwater resources in India by the Central Ground Water Board was published in 1995, is based primarily on data from 1989-1990 and contains no information on actual water level changes (Central Ground Water Board 1995). Furthermore, in most states groundwater monitoring data are insufficient to accurately depict water level changes at a local level even if the data were made generally available (Moench 1994; World Bank 1998, Janakarajan, 2001).

Given the lack of detailed monitoring data, our approach to estimating water level changes in the study areas was to collect survey information on the original and current depths of sample wells. These data indicate that water level declines have been significant both within and outside canal and tank commands.

Declining water levels are clearly indicated by the change in original and current well depths for both the Palar and Noyyal basins. These data are presented in the two graphs below and are based on a survey of 237 wells in eight villages for the Palar and 171 wells in four villages in the Noyyal conducted between 1998 and 2000 (see Figures 7 and 8). The data combine wells located in both dry and 'wet' lands. The data show that wells in both basins have been deepened over time. The increase in depth is particularly pronounced if the bores drilled within dug wells are included. In the Palar basin, almost 60% of wells were initially less than 30 feet deep, now including the depth of bores less than 30% are. Originally no wells were greater than 100 feet deep, now over 14% are. The change is even more dramatic in the Noyyal basin where, originally almost 60% of wells were less than 40 feet, now only 17% are; and further, more than 30% exceed 100 feet in depth.

Figure 7 Change in the Original and the Current Depths in the Palar Basin

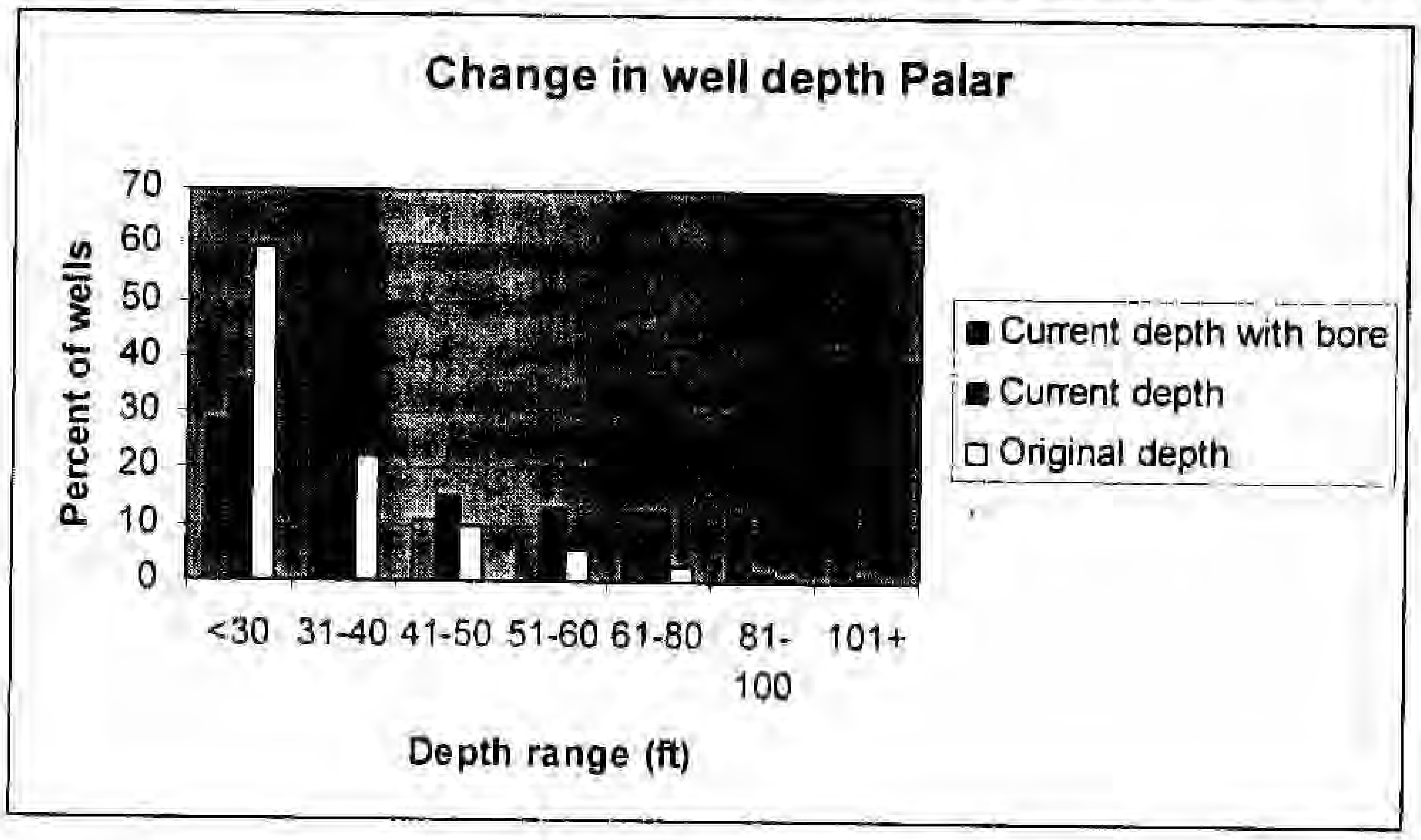
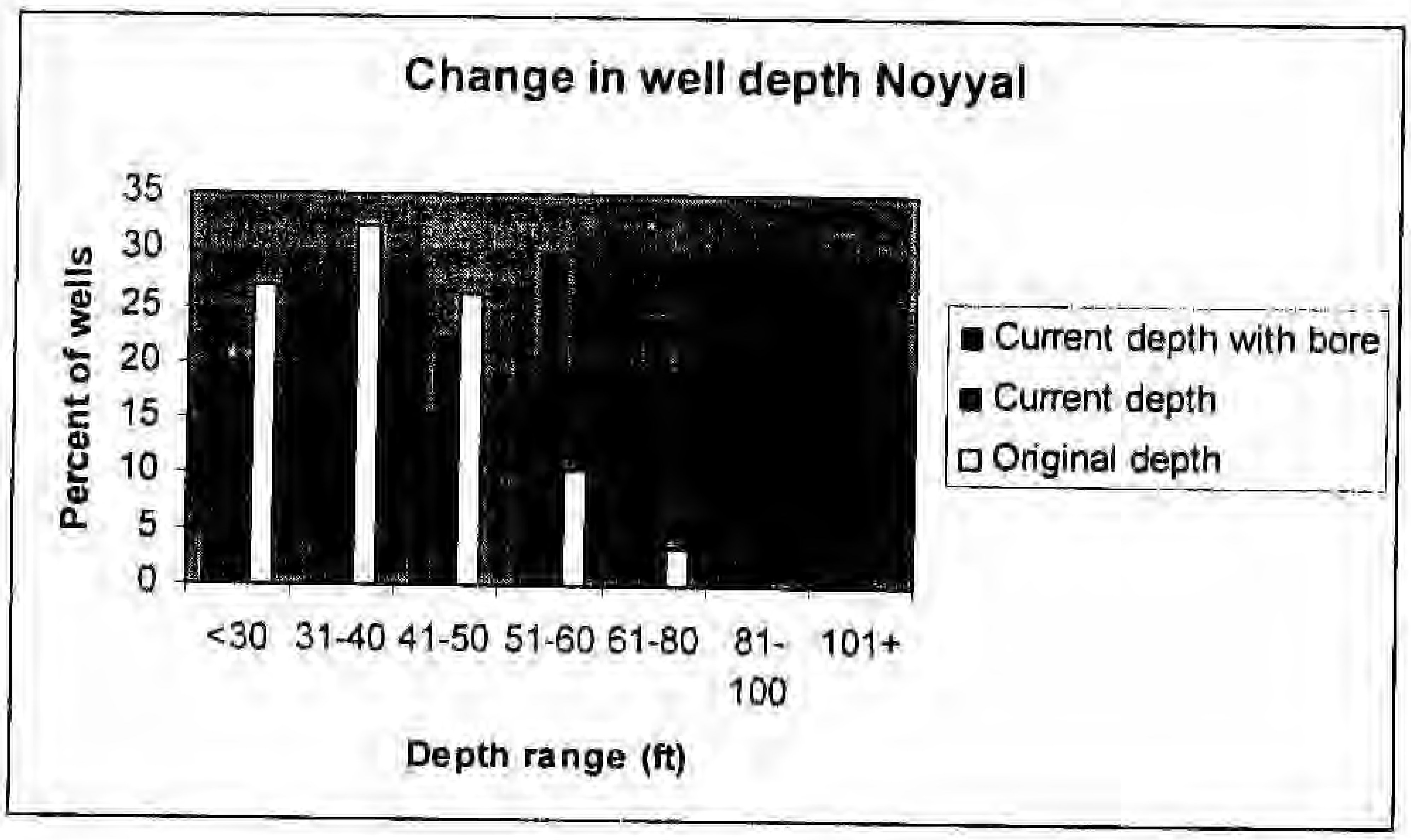


Figure 8 Change in the Original and the Current Depths in the Noyyal Basin



In addition, to the overall water level declines, earlier studies indicate that the 'original depth' to which wells need to be dug has increased over time – a 'new comer' has dug deeper than his predecessor had to, say 10 years ago (see Janakarajan 1997a). This is confirmed by data from the current survey also. In the Palar basin, the average original depth of the sample wells dug before 1960 was 30.2 feet. It rose to 35.8 feet for wells dug between 1961 and 1970, went up to 41 feet for wells dug between 1971 and 1985, and has averaged 69 feet for all wells dug subsequently. Similarly, in the Noyyal basin, the average original depth of sample wells dug before 1960 was 42.6 feet while the depth of wells dug after 1985 averages 66 feet. If one includes bore wells (which are more common in the Noyyal than Palar basin), the depth has increased from 100 feet between 1960-1970 when the first bores were installed to 260 feet in the post 1985 period. For the Noyyal basin this suggest an annual rate of water level decline of approximately 10 feet.

BOX 2 PALAR BASIN: VILLAGE: KATHIAVADI; SAMPLE WELL CODE NO: KYD 40

This well was dug in 1938 with a depth of 15 feet. Between 1950 and 1985 it was deepened six times to a total depth of 39 feet. An electric pump replaced the manual lift during the mid 1960s. There are three adjacent wells located within a radius of 150 feet, whose depths were initially around 30 feet. A series of droughts in the late 1980s caused all the well owners to deepen their wells. By 1992, the depth of the sample well was 50 feet and it had both vertical and horizontal bores installed within it. This caused two of the adjacent wells to dry up and reduced yields in the third. Their owners now lack the financial resources to deepen their wells. In contrast, the owner of the sample well is irrigating about 5 acres of his own land and is selling water to the others so that they can irrigate another two acres in each season. This is the clear case of competitive deepening where one well owner has been able to maintain or increase his prosperity while others are reduced to purchasing water

Changes in the well depth have been accompanied by changes in the water lifting technologies. In the Palar basin, of the 253 sample wells surveyed, 191 reported *kavalai* (bullock bailing lift) as the original technology, only one of which was still reported to exist at the time of the survey (that too not in use). Similarly, in the Noyyal

BOX 3: NOYYAL BASIN: VILLAGE: SA PALAYAM; SAMPLE WELL CODE NO: SAP 2

This well owner initially had an open well and used it until 1980. This well was 70 feet deep with 6 vertical and 6 side bores. The well stopped yielding water during a drought in the 1980s despite an investment of over 3 lakhs. It was permanently abandoned in 1990 when neighbours installed 250 feet deep bore-wells. At that point he also decided to install deep bores. Over the last 10 years he has installed 10 bores in different part of his land to depths of between 300 and 700 feet. Out of these only two, the deepest and one other, supply water at the moment and more than 25 bore-wells around his well have dried. He has spent Rs.5 lakhs on all these bores and can now cultivate 8 acres of coconut and tobacco out of his total 20 acre land holding. As a rich farmer who also owns a tobacco processing company, he has no debts. His income is, however, derived primarily from the tobacco company (which employs 100 women), not farming. During our interview, he proudly informed us that his neighbouring farmers decided to sell their land because of drying up of their bores.

basin out of 181 sample wells121 wells reported *kavalai* as the original technology while only one operational at the time of the survey. This is probably a function of two factors; water level declines which reduce the functionality of manual lift devices within dug wells, the spread of mechanized pumping technologies and the necessity of using mechanical pumps in bore wells. It is also interesting to note that the number of wells with no water lifting device (WLD) has gone up considerably over time, from 3 (as per the original WLD) to 71 (as per the current WLD) in the Palar basin and nil to 19 in the Noyyal basin. These are the wells, which have been deepened but subsequently abandoned either due to lack of supply or due bad water quality.

As illustrated in the accompanying boxes, declining water levels have led to extensive competition between well owners (see Boxes 2 and 3). The vast majority of farmers have deepened their wells several times. In addition, because many farmers have installed horizontal as well as vertical bores, the impact on water availability in adjacent wells is often severely affected. While disputes over water and the deepening of wells are common, no dispute was reported in our survey due to side-bore installations even when they penetrated under adjacent lands. Despite the extent of competition and conflict over well deepening, farmers do not seek justice through the court of law because property rights in groundwater are known to be ambiguous and indeterminate. This situation has heavy negative implications for future users and adds tremendously to the costs faced by the current users (see also, Janakarajan 1997b). One final point is important to mention before concluding this section, competitive deepening is virtually absent in pollution affected villages, since farmers do not have incentive even to use groundwater for irrigation.

Section 5: The Impact of Water-level declines on well technology

Dropping water levels and competition have major implications for the types of well technology that can be used. This has had a variety of impacts.

First, there has been a change in the design and type of wells dug. Conventional, large diameter round or square wells cannot be used when water levels fall and new technologies for both wells and pumping have spread in recent decades. Now a large majority of wells in the Palar river basin are fitted with both vertical and horizontal bores and in the Noyyal most farmers now install deep bores from the surface. Hydraulic drilling companies have spread in large numbers in the Noyyal region and generate large profits from the continuous business available there. This kind of well digging technology has substantially contributed to competitiveness and over-pumping of groundwater.

Second, well deepening and the use of high power motors and compressors have a huge impact on energy demand. Until three decades ago, bullock bailing was the main method of water extraction. That practice is almost extinguished. It was followed, until the mid 1980s, by pumping with low capacity (3.5 HP) pumpsets. Now a 10 HP motors are common, particularly in the Noyyal, and in many cases farmers use more than one motor in a same well. All this has been facilitated by the State's policy of free power supply.

Third, declining water levels have encouraged increases in use efficiency. Until the late 1980s, open channels were used for conveying water from wells to fields. Now farmers often use underground pipelines and hose pipes.

Fourth, high well and equipment costs disproportionately affect small farmers who own about 60% of wells in the State. While large farmers have the resources to survive unsuccessful investments in well digging and well deepening or persistent droughts (as occurred in the 1980s), for a small farmer the losses are often unsustainable.

It is worthwhile looking at the impact of competition on changing technologies in more detail. The case of the Noyyal illustrates the on-going changes well. Unlike the Palar basin, groundwater is extracted from deep bores in the Noyyal basin. In some locations in Noyyal, bore-well depths approach 1200 feet. Due to the hard rock nature of the geology, yields in such wells are very low making continuous pumping difficult or impossible. Wells need time to recuperate – for gradual seepage from fractures in the bedrock to re-establish a water column – before they can be pumped again. To assist in this, farmers use compressor technology, which allows them to run pumps even when there is very little water.

Approximately 95% of the bore wells in this basin are fitted with compressors. With compressors, the amount of water that could normally be pumped in one hour takes six to seven hours. Since the yield is low, the flow is insufficient to be used directly for irrigation or for sale. As a result, water is pumped and stored in cisterns – either adjacent dry dug wells or concrete tanks of up to 100, 000 liter capacity. It is pumped again for irrigation or for sale. The electricity consumption in these bore-wells is double or triple due to: (a) the use of compressors to run pump motors, (b) running of motors for long time periods to pump small amounts of water and (c) the need to pumping the same water twice (once from the bore and again from the open well tank where the water is stored).

Because of low yields and compressor technologies, the way water is pumped and stored has major implications for both energy use and the overall cost of obtaining groundwater access. Based on sample survey data collected in four villages of this basin, we have developed a typology that illustrates the diverse techniques and equipment required (see Table 6). As Table-6 demonstrates, farmers often need to invest in high capacity pumps and in the substantial storage structures. Low yields also often require farmers to drill multiple bores within dug wells. Finally, in many cases (37% of the sample wells) the same water is pumped twice, once directly from the well and once again for irrigation or sale.

Section- 6 Costs and investments in wells

The variety of pumping and well technologies now in use has major implications for the cost of obtaining access to groundwater. The cost of a well is much lower in the Palar basin compared to the Noyyal., because water tables are higher and the more expensive compressor and storage technologies are not required. In the Palar basin, the average cost of pumping equipment is Rs.14600 per well (including motors, pumps and other related accessories). In the Noyyal equipment costs average Rs.31,000. In addition, each successful bore-well requires at least five or six trial-bores. Furthermore, around each operating bore or open well, there are several closed bore points, which have stopped yielding water. There is no assurance that successful wells will remain productive. Indeed, according to the latest available statistics for Tamilnadu (Government of Tamilnadu, Season and Crop Report, 1997-98), the wells not-in-use constitute about 10% of the total number of wells in the State. Many wells have been abandoned after investing over Rs.100,000. (Janakarajan, 1997a). Eventually, all the investments that have gone into wells accumulate to pose a heavy burden on the community as a whole as well as on an individual farmer. The cost is not, however, just at the community level. Since electricity for agricultural pump-sets is free in Tamil Nadu, this cost is paid by the tax payers as a whole. Farmers face no marginal cost and do not hesitate to pump water even if the delivery of water is quite low.

As a part of the survey in the Palar and Noyyal river basins we collected basic information on the investments farmers have made to first get and subsequently maintain access to groundwater. These data are discussed below. Before presenting the results, it is important to note key data limitations. In most instances, the figures well owners gave are below current prices. As a result, the current value is likely to be higher than the data suggest. In addition, significant difficulties were faced in gathering this information due to memory lapses, sale, inheritance and transfer of wells to others. In consequence, data for some sample wells are not included in our analysis.

Table 6: Typology of wells with different pumping and storage equipment

Well, Pump and Cistern Characteristics	Number of Wells in Village			
	Kar	Ora	Sou	Uga
Deep bore well from which water is pumped with one motor and a compressor in order to store water in an independent well - only to pump again for irrigation (twice pumped)	8	2	16	15
Deep bore well from which water is pumped with one motor and a compressor in order to store water in an independent well - only to pump again for water sale for industries (twice pumped)	0	0	0	3
Deep multiple bores (up to 3) simultaneously operated with one high power motor (10 HP) along with one compressor in order to store water in a deep open well - only to pump again for irrigation (twice pumped).	5	0	3	8
Deep multiple bores (>3) simultaneously operated with 2 high power motors (of up to 10 HP each) along with two compressors in order to store water in a open well - only to pump again for irrigation (twice pumped)	1	0	0	0
Shallow well which is operated (with up to 5.00 HP motor) for direct irrigation - own use (once pumped)	6	5	6	7
Shallow well which is operated (with up to 5.00 HP motor) for water sale to industries and irrigation (once pumped)	0	0	0	2
Deep well which is operated (with up to 7.5o HP motor) for direct irrigation - own use (once pumped)	5	7	18	10
Deep multiple - vertical bores installed within a dug well - operated with a high power motors - used for own agriculture - (once pumped)	5	0	2	4
Multiple deep bores (up to 4) from which water is pumped simultaneously with a single high power motor (of up to 10 HP) with one compressor in order to store water in a concrete tank (capacity is 100,000 litres) both to sell water for urban industrial use as well as to pump for own agricultural use (twice pumped)	2	0	0	1
Multiple deep bores (up to 4) from which water is pumped simultaneously with a single high power motor (of up to 10 HP) with one compressor in order to store water in a concrete tank (capacity is 100,000 litres) but used for own industries – D/B), Twice pumped	3	0	0	0
Multiple deep bores (up to 4) from which water is pumped simultaneously with a single high power motor (of up to 10 HP) with one compressor in order to store water in a concrete tank (capacity is 100,000 litres)- but water is used for own agricultural use by letting water through gravity flow. (once pumped)	1	0	0	1
Shallow wells not – in –use	12	6	9	8
Total of all typologies	48	20	54	59

Village Names: Kar = KARAIPUDUR; Ora = ORATHAPALAYAM; Sou = SOUTH AVINASHIPALAYAM; Uga = UGAYANUR.

Source: Main survey, 1998-00

Our data indicate that the cost incurred on wells by individual farmers is high and and often disproportionate to level of farm income generated. In addition, it varies between wet lands (those located in the command of surface systems) and dry lands. The amount spent per well in the wet and dry lands land of the Palar basin (aggregate for 8 sample villages) is Rs.72000 and Rs.86000 respectively at current prices. Wells in 'wet' lands tend, however, to supply much larger command areas and require lower supplementary equipment investments. As a result, although the well costs differ by less than 20%, the net costs are higher -- equivalent to Rs.70,000 and Rs.95,500 per hectare in the wet and dry lands or 36% higher in dry lands. Costs incurred in the dry land wells are much higher because the water table has declined much more steeply than in the wetlands. In the Noyyal river basin, average current cost per well is much higher (Rs.221,000) and the cost incurred per hectare of net irrigated area is higher as well Rs.188,000 (see Tables-7 and 8).

Table 7 Costs of well irrigation in the wet & dry land wells of the Palar basin

Village	No.of sample wells	Original cost per well (Rs)	Average current cost per well (Rs)	Original average cost per hectare of NIA (Rs)	Current average cost per hectare of NIA (Rs)
Kathiavadi	13	2615	91,000	'1935	67,000
Poondi	15	8733	79,000	6488	58000
Gudimallur	7	857	86,,000	534	54000
Periavarigam	5	8800	58,000	9205	61000
Solur	5	1800	51,000	5556	159000
Damal	38	13289	75,000	4297	24000
RN Pettai	8	4875	65,000	7800	104000
NM Pattu	8	6250	87,000	2317	32000
Average		8242	72286	4767	69875
Costs of well irrigation in the dry land wells of the Palar basin					
Kathiavadi	27	11074	116,000	8413	88000
Poondi	7	16857	84000	19250	96000
Gudimallur	12	5583	79000	9293	131000
Periavarigam	25	5400	93000	6139	105000
Solur	16	7063	93000	7766	103000
Damal	11	16000	81000	6780	35000
RN Pettai	34	10471	76000	19734	143000
NM Pattu	18	10444	68000	8835	58000
Average		10362	86250	10776	94875

Note: Solur, Periavarigam, Gudimallur and Poondi are affected villages due to discharge tannery effluent, where groundwater is badly contaminated; Among other villages, while Kathiavadi is partially affected, Damal, NM Pattu and RN Pettai are not affected. Source: Main survey, 1998-00

Table-8 Costs of well irrigation in the Noyyal basin

Village	No.of sample wells	Original cost per well (Rs)	Average current cost per well (Rs)	Original average cost per hectare of NIA (Rs)	Current average cost per hectare of NIA (Rs)
SA Palayam	54	9907	230333	7778	180837
Ugayanur	59	22797	199559	20345	178097
O Palayam	20	9000	202450	6020	135418
K Pudur	48	21000	252521	21279	255879
Average		15676	221216	13856	187558

Note: O.Palayam and K Pudur villages are affected due to discharge of effluent from the dyeing and bleaching industries, where groundwater is badly contaminated; Other two villages, namely, SA Palayam and Ugayanur are not affected.
Source: Main survey, 1998-00

Two points are worth noting from the above tables. First, the costs incurred per well and per hectare are high. According to the Ninth Five year Plan Document (1997-2202), the cost incurred to create one hectare of major and medium irrigation potential by the Government works is Rs.40166 at current prices. (Government of India, undated). In our survey, individual farmers spend Rs.70,000 and Rs.95000 to get one hectare of net area irrigated by wells in the wet and dry lands respectively in the Palar basin. In the Noyyal basin the costs per hectare (average Rs 190,000) are far higher -- approximately 4.7 times what the Government has spent to create one hectare irrigation potential under major and medium irrigation projects. Newcomers would need to spend this to develop one hectare of net area irrigated by well. In addition, they have to bear the risk of failures due to water level declines, drought or problems in locating a productive zone. There is substantial variation between villages. Local groundwater conditions and the presence or absence of pollution have a large impact on the costs of wells and irrigated area. Well irrigation has become a gamble. Not all those who invest in wells are successful. Many fail and lose in the race of competitive deepening or wells go into disuse due to pollution. Many well owners either sell their land or become trapped in debt as they try to develop new wells. A new dimension of inequality emerges as a result. Those who have, so far, been able to keep up in the competitive deepening race have emerged as potential water sellers, others are reduced to the status of water purchasers (Janakarajan, 1997b, Vaidyanathan, 1996).

Section-7 Water Markets – Conflicts and Contradictions

As the cost of wells has increased, the sale of groundwater in the rural areas has become a common phenomenon. Like joint well ownership, the emergence of water markets in rural areas is a spontaneous institutional response to scarcity, which facilitates sharing of scarce groundwater resources. The magnitude of water markets and the terms and conditions under which they operate vary greatly depending upon availability of groundwater, water quality, soil conditions and a variety of other factors. While a full review of water markets is beyond the scope of this chapter, a number of points are important to note.

First, the price paid for water is often dictated by the nature of the water supplier. If the State is the water seller, the price individuals are willing to pay is insignificant in India compared to what is paid to a private seller. As the Committee on Pricing of Irrigation Water reports, "At present, the actual gross receipts per hectare of area irrigated by major and medium projects is barely 2 per cent of the estimated gross output per hectare of irrigated area…"(Planning Commission, Government of India, 1992). On the other hand, farmers pay up to one-third of their gross produce or up to Rs.40 per hour towards water when supplied by a private well owner (Janakarajan, 1992, and Janakarajan, 1997a).

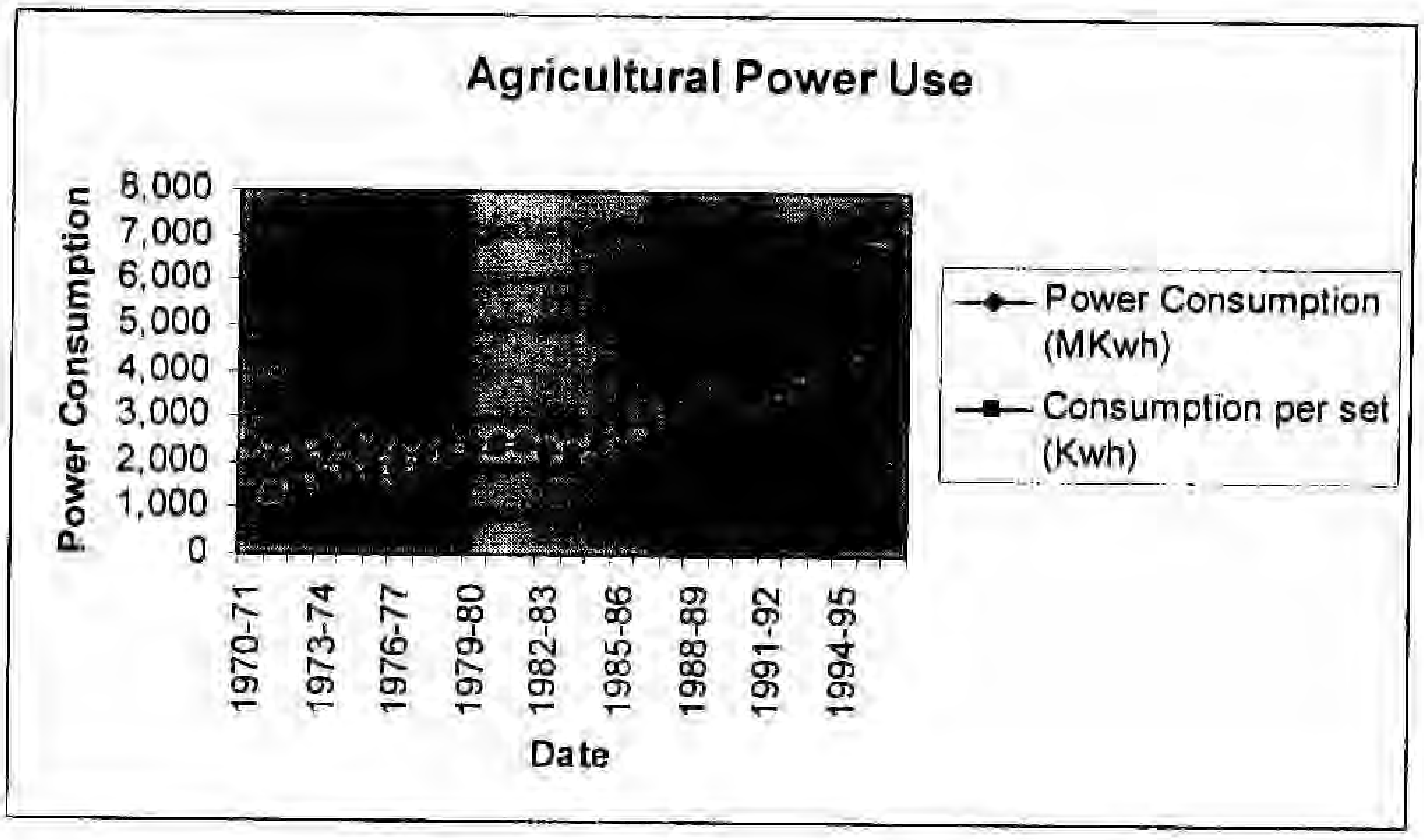
Second, private water sellers pay very little or nothing for power to the state particularly in Tamilnadu and Haryana. As the table below indicates, electricity tariffs in Tamil Nadu were first subsidized for small farmers, then shifted in the early 1980s to a horsepower basis. Since 1989-90 power for agricultural users has been supplied free. Power consumption in agriculture has, as a result, been increasing. This is not, however, due primarily to expanding pump numbers. Although pump numbers have been increasing, the time series data clearly indicate that per pump set power consumption has been increasing at a faster rate than the total increase in agricultural energy consumption. This change is particularly evident from the year free electricity was introduced (see Figure 9). This may be due to long term decline in the water table or low delivery of water from the wells encouraging farmers to run pump sets for longer hours. It strongly suggests that farmers have the tendency to operate their motors even under uneconomical conditions due to the zero operating cost. Furthermore, because the owners of functioning wells are not paying the cost of power, they disproportionately capture the benefits of power subsidies. Based on our survey of 38 well owners in the Noyyal basin we estimated that the 23 farmers who pump water only once receive a power subsidy of Rs.7110 while the 15 rich and successful well owners who pump the same water twice receive approximately Rs.53,478. Existing power subsidies are heavily biased in favor of the wealthy.

Table - 9 Electricity tariff and Consumption of Electricity per Pump Set in Tamilnadu 1970-71 to 1996-97

Year	Total energy consumed for ag. Pump sets (mu)	Number of electric pump sets	Energy consumed /pump set (units)	Tariff charged for agricultural pump sets
1970-71	1,241	5,29,932	2,342	8 paise / unit
1971-72	1,269	5,94,169	2,136	9 paise / unit
1972-73	1,430	6,49,241	2,203	11 paise / unit
1973-74	1,576	6,81,205	2,314	11 paise / unit
1974-75	1,847	7,06,914	2,613	11 paise / unit
1975-76	1,675	7,42,745	2,255	16 paise / unit
1976-77	1,697	7,73,702	2,193	16 paise / unit
1977-78	1,786	8,09,606	2,206	Big farmers - 16 paise / unit Small ----- - 14 paise / unit
1978-79	2,104	8,40,557	2,503	Big farmers - 14 paise / unit Small ----- - 12 paise / unit
1979-80	2,186	8,87,227	2,464	Big farmers - 14 paise / unit Small ----- - 12 paise / unit
1980-81	2,299	9,19,162	2,501	Big farmers - 14 paise / unit Small ----- - 12 paise / unit
1981-82	2,354	9,45,520	2,490	Big farmers - 15 paise / unit Small ---- - 12 paise / unit
1982-83	2,230	9,65,017	2,311	Big farmers - 15 paise / unit Small ---- - 12 paise / unit
1983-84	2,200	9,82,606	2,239	Big farmers - 15 paise / unit Small ---- - 12 paise / unit
1984-85	2,415	9,82,606	2,458	Big Farmers:Rs.75/HP/year Small ...... :Rs.50/HP/year
1985-86	2,840	10,33,533	2,748	Big Farmers:Rs.75/HP/year Small ...... :Rs.50/HP/year
1986-87	3,114	10,74,184	2,899	Big Farmers:Rs.75/HP/year Small ...... :Rs.50/HP/year
1987-88	3,136	11,16,177	2,810	Big Farmers:Rs.75/HP/year Small ...... :Rs.50/HP/year
1988-89	3,524	11,84,450	2,975	Big Farmers:Rs.75/HP/year Small ...... :Rs.50/HP/year
1989-90	3,740	12,35,941	3,026	Big Farmers:Rs.75/HP/year Small ...... :Rs.50/HP/year
1990-91	3,974	13,18,671	3,014	Rs.50 / HP / annum for ≤ 10 HP and Rs.75 / HP/ per annum for >10 HP
1991-92	4,451	13,59,748	3,273	Since 1991 free supply for all
1992-93	5,160	14,03,673	3,676	
1993-94	5,618	14,45,951	3,885	
1994-95	6,228	14,88,469	4,184	
1995-96	6,626	15,28,807	4,334	
1996-97	6,910	15,67,317	4,409	

Source: Compiled from various issues of Tamilnadu Electricity Board – A Glance.

Figure- 9 Power Use in Agriculture – Total for Agriculture and per Pump Set



Third, there is a high degree of polarization between water sellers and purchasers. In a separate study of the Vaigai basin, (Janakarajan, 1997a) found that that a little more than three-fourths of the water purchasers are poor farmers whose holding size is less than one hectare. A separate study in the Palar basin indicated that the extent of inequality in the distribution of land across all the cultivators (excluding landless population) is extraordinarily high, as reflected in a Gini coefficient of concentration of O.88. Differences in Gini coefficients calculated separately for water purchasers and water sellers are, however, relatively small (0.34 and 0.40). This suggests that the 'between-group' component of inequality (viz., between water sellers and water purchasers) is far greater than the 'within-group' component (Janakarajan, 1992). Furthermore, a vast majority of the water purchasers belong to the socially deprived castes; Scheduled castes, the most deprived in the social hierarchy in India, constitute 27.3% of the water purchasers (Janakarajan 1997a). This suggests that the agents involved in the water deals are sharply polarized socially as well as economically with unequal bargaining capacity.

The disparity between water sellers and purchasers often leads to subtle conflicts. Take, for example, the common informal rule that a water purchaser should purchase water only from the closest well owner or if all involved agree from the next nearest well owner. This rule is intended to avoid conflicts since increasing distance would require transporting water through the field channels of other farmers. It, however, places water purchasers at the mercy of adjacent landowners and conflicts often emerge when the rule is violated (Janakarajaan, 1992). The rule, in effect, places adjacent well owners in a monopoly position. Furthermore, purchasing water from distant wells is difficult because the water purchaser needs to have equipment (such as a hose for transporting water) but has little is no guarantee that sellers will supply them regularly (Janakarajan, 1997a). Second, unequal trading relationships in water markets often result in exploitation of the weaker agent. Water purchasers are often required to supply free or under-paid labour services to sellers. Refusal is impossible because well owners can retaliate by cessation of water supply in the middle of a season (Janakarajan, 1992). In several cases in the Vaigai basin, payments for water were made through labour compensation and crop sharing. While this can have advantages for cash poor water purchasers and (in the case of crop sharing) spreads risk, it is also open to abuse. Therefore, water markets become interlocked with the other labour, credit and product markets (Janakarajan, 1992 and 1997a). In addition, there are instances in which the water purchasers were forced to lease-out their parcels of land in favour of the water sellers, at terms dictated by the latter. This is the case of *reverse tenancy* in which a lessee is seemingly more powerful than a lessor. Overall, although, instances of open conflict between water purchasers and water sellers are infrequent, the former are often resentful of the latter. In addition, in some villages, water sellers collude in fixing the price for water, which again generates conflict with water purchasers (Folke, Steen, 1996, Janakarajan, 1992).

Agricultural water markets may now be declining. In the Noyyal river basin, water sale for agriculture was never significant – but water sales to industry are common. In the Palar basin, local agricultural water markets flourished until approximately a decade back. Since then, there appears to have been a significant drop in the extent of water sale (see Table 10). Farmers attribute this to progressive declines in the groundwater table which make it difficult to irrigate even their own crop and to increases in pollution which have reduced all agricultural activities significantly. In other words, water sale has generally been a supplementary activity (the sale of excess supplies) with the primary goal of well ownership being to supply one's own needs first. Table-10 gives information surveyed wells reporting water sales in the Palar river basin. Roughly 10% of the sample wells in three villages reported water sales, supplying water to about 35 acres of land in an agricultural year. Only three of the eight villages in the Palar river basin had wells that reported significant water sales. In the remaining five villages, all of which are affected due to tannery pollution, no water sale was reported.

TABLE 10 EXTENT OF WATER SALE IN THE SAMPLE VILLAGES AS REPORTED BY THE SAMPLE WELLS IN THE PALAR BASIN

Village	Total number of sample wells	Number of sample wells reporting water sale	Gross area to which water was sold in 1998-99 (acres)
Damal	49	7	20.50
Kathiavadi	41	1	2.50
Ramanaicken Pettai	43	5	11.70
Total	133	13	34.70

(Source: Main survey, 1998-00)

The decline in agricultural water markets does not necessarily imply a decline in overall water market activity. In the Noyyal river basin, there is a major water trade between rich well owning farmers and urban industries (mainly dyeing and bleaching units). From two of the sample villages, viz., SA Palayam and Ugayanur, water is sold from 21 deep bores (depths of which go up to 1400 feet) to urban industries. According to our estimate, easily 100 million liters of water is transported daily from the villages around Tiruppur town. This can generate significant revenue -- the rate per 12000 liter tanker varies from Rs.75 to Rs.400, depending upon the season and the quality. Most of the wells were initially agricultural but have now converted into commercial wells selling water. They belong to rich farmers who also irrigate a part of their holdings. Some industrial owners also own their own deep bore wells in this area. The effect of water sales on surrounding users appears disastrous. Neighbouring well yields have declined significantly and family members from these farming households have almost stopped cultivation and are seeking jobs in the urban industries.

Overall, the evidence from Tamil Nadu indicates that local water markets are not a solution for growing water scarcity and, at least in the context of free power supply, have a limited impact on the incentive to reduce demand. At present, water markets seem to aggravate the problem of inequality and reinforce backward relations.

8 A Return to the Larger Perspective

The detailed case study of groundwater issues in Tamil Nadu presented above relates closely to core issues facing groundwater development and management at a national level in India and Nepal.

That groundwater can play a critical role as a buffer against drought needs no elaboration. It is also now well established that crop yields in groundwater irrigated areas are generally higher than those in areas irrigated by surface sources and that groundwater access plays a critical role in agricultural development. In addition, strong arguments can be made that access to groundwater can play a major role in poverty alleviation and has done so in locations such as India (Moench 2001). Access to groundwater reduces agricultural risk. By doing so, it can enable farmers (whether poor or wealthy) to begin a gradual process of agricultural intensification and accumulation that allows them to move out of poverty. The problem with groundwater, as this paper documents, is that access is not uniformly distributed. Even in areas where groundwater is close to the surface and major investments are not required to obtain access, groundwater development tends to parallel existing resource differentials within society. Innovative farmers, farmers with exposure to new ideas and sufficient land to test them in their own plots (equivalent to saying 'wealthy farmers'), tend to be the initial adopters. As a result, the initial benefits from groundwater development tend to disproportionately favour those who are already economically well situated. This differential is exacerbated as the cost of accessing groundwater resources increases due to water level declines, pollution or other factors. Early adopters have often accumulated sufficient resources to diversify their operations, to afford new equipment and to be able to deepen or drill wells as the water table declines. Later adopters and those whose overall resource base (land, education, access to capital, etc...) is limited, face major difficulties maintaining access. As a result, economic differentiation within communities increases. Differentiation and competition over scarce resources increase conflict. The situation is particularly exacerbated by the fact that groundwater access is dependent primarily on an individual's context. Unlike tank maintenance, it doesn't depend on community action. Furthermore, once an individual has access to groundwater, the incentive they face to contribute to community water supply systems is, for all practical purposes, eliminated. As a result, community systems erode and the 'safety net' present for the poor in joint systems such as tanks, 'spring channels' or large surface irrigation projects erodes with them. In this context, groundwater, or rather the struggle to maintain access to it, can contribute to poverty and further socio-economic differentiation.

The situation in Tamil Nadu is affected by the hard-rock nature of the geology. Because wells are dug into hard-rocks where storage is low and well yields depend heavily on chance (whether or not wells hit productive fracture zones), the dynamics of groundwater access are different from areas underlain by alluvial aquifers. Several factors contribute to this difference:

1. **High, location dependent, risk**: The risk of investing in unproductive wells is far higher in hard rock areas than in alluvial areas. In most alluvial areas, regional water levels are the primary factor determining the ability to access groundwater – one just needs to drill wells to sufficient depths. In hard rock areas, however, fracture patterns are often highly variable. As a result, the chance of success in tapping a productive zone depends on the financial resources to drill multiple bores *and* on a large landholding with multiple locations where it may be possible to drill a well.

2. **Low storage**: The low storage in hard rock areas heavily biases benefits toward early adopters. Because storage is low, water level declines occur rapidly and those who dig or drill the first wells are far more likely to obtain water at a reasonable cost than those who attempt to do so later.

3. **Low well yields**: Because well yields tend to be low in hard rock areas, little surplus is generally available beyond the amount needed to irrigate immediately adjacent lands.

Low well yields, low storage and the high risk nature of hard rock aquifers have important implications for the nature of water markets. Many of the studies on water markets in India have been done in the deep alluvial aquifers of Gujarat. There, although water levels are falling, the capacity to pump water from any given well tends to be relatively high and relatively uniform within a given area. As a result, small, medium and even large farmers are often able to reliably pump significantly more water than they can use for irrigation on their own lands. There is, as a result, often a strong incentive to sell excess supplies. Since power is charged at a flat annual rate based on pump horsepower, there is no marginal cost and sale of any excess supply at any rate reduces average costs. In many such locations, the bargaining position of both buyers and sellers is relatively equal. This type of dynamic can lead to incentives for water sales at rates below the full cost of well development (Shah 1993; Moench 1995; Moench 1996). The situation is fundamentally different in hard rock areas where well yields are low and often vary greatly across seasons. In this situation, surpluses are far smaller and tend to vary greatly across seasons and locations. It is a seller's market in which the bargaining position of water buyers is weak. This is probably a major factor underlying the interlocking of other agricultural markets with those for water.

Where does this leave us with respect to global and local debates over the role of groundwater markets? This role is discussed in detail in Moench and Janakarajan (forthcoming), which deals with markets and commodity chains. It is, however, important to emphasize the observation from the fieldwork that water markets in Tamil Nadu and in the rest of India are self-initiating institutions. They weren't created by the government interventions and their characteristics are difficult to influence through government policies. They *exist* as informal institutions outside the formal legal or regulatory frameworks of the Government. In addition, their characteristics vary greatly between regions and locations. Furthermore, as conditions change the characteristics of water markets are change with them. As a result, while it is important to understand the impact of groundwater markets on access to a key resource for local populations, there probably isn't much that can be done to influence their dynamics under existing circumstances.

The above observation on groundwater markets raises the question of how civil society is going to respond to escalating and competing demands on a shrinking groundwater resource base? Tushaar Shah illustrates the issue at a national scale in a diagram he prepared for the book *Groundwater and Society* (Burke and Moench 2000) p. 66. This diagram illustrates the transitional nature of groundwater development and use across India. Initially groundwater development catalyzes change and the development of an intensive agricultural economy. Then, as development levels reach or exceed sustainable levels, the economy that has grown based on intensive groundwater irrigation must transition. In some areas, intensive agriculture based on groundwater use may be sustainable. In other areas, limitations on the physical availability of water will force a transition. How this transition occurs is, perhaps, the largest question facing groundwater management. Will it be possible for populations to make a planned (or at least smooth) transition to other forms of economic activity and limit groundwater extraction to sustainable levels – or will the transition be driven by the types of dynamics currently seen in the case of Tamil Nadu? In the Noyyal basin, small well owning farmers in Orathapalayam and Karaipudur have been so badly affected by water pollution that they are being force out of agriculture and are becoming job seekers in the urban areas. A similar dynamic is occurring in Ugayanur and SA Palayam villages where farmers have been driven out of agriculture due to their inability to keep up in race of competitive well deepening. In SA Palayam 16 out of the 54 sample wells have gone dry and are not in use. Their owners have lost in the race of competitive deepening and are heavily indebted. Over 60% well owners in Tamil Nadu are small and marginal farmers with landholdings of less than 5 acres. Their economic survival is threatened by pollution and groundwater overdraft. How rural populations of this type can transition to more sustainable livelihoods is a critical question throughout much of India.

Two final issues have to do with the question of power subsidies and pollution.

As documented above, most of the existing power subsidies are captured by the wealthy. In addition, the provision of free power encourages highly inefficient water use practices and groundwater overdraft. This is a clear case where policy reform is required. Reform must, however, also address the issue of transition. At present, even if Rs.0.50 is charged per unit of electricity consumption, many small farmers will have to close down their wells because of uneconomical conditions (Janakarajan,S, forthcoming). Continuing subsidies that primarily benefit the wealthy and encourage unsustainable patterns of groundwater use would be counterproductive – but the displacement caused by policy reform must also be recognized and addressed.

Pollution is also a critical issue. This will not be addressed through policy reform alone – existing pollution laws in Tamil Nadu, as in the rest of India, are sufficient to enable action. They aren't, however, generally enforced. As we argued in our earlier book *Rethinking the Mosaic* (Moench, Caspari et al. 1999), social auditors, the independent voices that raise uncomfortable truths in society, are essential to build pressure on governments and others to act.

REFERENCES

Amarasinghe, U., L. Mutuwatta, et al. (1999). *Water Scarcity Variations within a Country: A Case Study of Sri Lanka.* Colombo, International Water Managment Institute: 29.

Bhatia, Bela, 1992. "Lush Fields and Parched Throats: Political Economy of Groundwater in Gujarat", *Economic and Political Weekly*, Vol.27, Nos 51 and 52, December, 19-26.

Burke, J. and M. Moench (2000). *Groundwater and Society: Resources, Tensions, Opportunities.* New York, United Nations.

Central Ground Water Board (1995). *Groundwater Resources of India.* Faridabad, Central Groundwater Board, Ministry of Water Resources, Government of India.

Dhawan, B. D. (1995*). Groundwater Depletion, Land Degradation and Irrigated Agriculture in India.* New Delhi, Commonwealth Publishers.

FAO (2000). *Agriculture: Towards 2015/30.* Rome, Food and Agriculture Organization of the United Nations, Global Perspective Studies Unit: 249.

Folke, Steen, 1996. *Cauvery Delta: Canal and Well Irrigationand Conflicts over land and Water*, unpublished.

Government of Tamilnadu, 1998, *Season and Crop Report for the year 1997-98*, Chennai.

Government of India, undated, Planning Commission, *Ninth Five year Plan 1997-2002, Vol-II, Thematic Issues and Sectoral Programmes.*

Harriss, john, 1982, *Capitalism and Peasant Farming: Agrarian Structure and and Ideology in Northern Tamilnadu*, OUP, Bombay.

Janakarajan, 1986. *Aspects of Market Inter-relationships in a Changing Agrarian Economy,* Thesis submitted for the award of the Doctor of Philosophy, University of Madras.

Janakarajan, 1992. 'Interlinked Transactiond and the Market for Water in the Agrarian Economy of a Tamilnadu Village', in S.Subramanian (ed) *Themes in Development Economics: Essays in Honour of Malcolm Adiseshiah,* OUP, Delhi.

Janakarajan,S. 1993. 'In Search of Tanks', *Economic and Political Weekly*, Vol.28, No.6.

Janakarajan,S. 1997a. *Conditions and Characteristics of Groundwater Irrigation: A Study of Vaigai basin in Tamilnadu*, Report of a research project sponsored by the Planning Commission, Government of India, MIDS, Chennai.

Janakarajan,S. 1997b. 'Consequences of Aquifer Over-Exploitation: Prosperity and Deprivation', *Review of Development and Change*, Vol.II No.1.

Janakarajan,S. 1999. 'Conflicts over the Invisible Resourcein Tamilnadu: Is there a way out?', in Marcus Moench, Elizabeth Caspari and Ajaya Dixit (eds), *Rethinking the Mosaic: Investigations into Local Water Management*, NWCF, Kathmandu and ISET, Boulder, U.S.A.

Janakarajan, 2000. Issues Relating to Official Data Base on Groundwater Resource in Tamilnadu, *Review of Development Change*, Vol.V, No.2, July-December.

Janakarajan, forthcoming, 'Populism, Myopia and Crisis', *Water Nepal*.

Ladha, J. K., K. S. Fischer, et al. (2000). *Imporving the Productivity and Sustainability of Rice-Wheat Systems of the Indo-Gangetic Plains: A Synthesis of NARS-IRRI Parnership Research*, International Rice Research Institute: 31.

Lindberg, Staffan, 1996. *While the Wells Went Dry - Tragedy of Collective Action among Farmers in South India*, a chapter for the anthology: "From Wild Pigs to Foreign Trees", mimeo.

Malik, R. P. S. (1993). *Electricity Pricing and Sustainable Use of Groundwater: Evaluation of Some Alternatives for North-West Indian Agriculture*. Workshop on Water Management: India's Groundwater Challenge, VIKAST, Ahmedabad, India., VIKSAT.

Moench, M. (1992). "Chasing the Watertable." *Economic and Political Weekly* **XXVII**: A171-A177.

Moench, M. (1992). "Drawing Down the Buffer." *Economic and Political Weekly* **XXVII**(13): A-7-A-14.

Moench, M. (1993). "Electricity Pricing and groundwater use efficiency: Critical linkages for research." *Pacific and Asian Journal of Energy* **3**(1): 121-129.

Moench, M. (1994). "Hydrology Under Central Planning: Groundwater in India." *Water Nepal* **4**(1): 98-112.

Moench, M., Ed. (1995). *Electricity Prices: A Tool for Groundwater Management in India*. Ahmedabad, VIKSAT.

Moench, M. (1996). *Groundwater Policy: Issues and Alternatives in India*. Colombo, International Irrigation Management Institute.

Moench, M. (2001). *Groundwater and Poverty: Exploring the Links*. Workshop on Intensively Exploited Aquifers, Royal Academy of Sciences, Madrid.

Moench, M. (2002). "Water and the Potential for Social Instability: Livelihoods, Migration and the Building of Society." *Natural Resources Forum* **forthcoming special issue**.

Moench and Janakarajan (2002) *Water Markets, Commodity Chains and the Value of Water*, Draft.

Moench, M., E. Caspari, et al., Eds. (1999). *Rethinking the Mosaic: Investigations into Local Water Management. Kathmandu,* Nepal Water Conservation Foundation and the Institute for Social and Environmental Transition.

Nanjamma, C. 1977. 'Adoption of the New Technology in North Arcot District', in. Farmer,B.H. (ed) *Green Revolution? Technology and Change in Rice Growing Areas of Tamilnadu and Sri Lanka*, New York, Macmillan.

Palanisamy,K, R.Balasubramanian and Mohamed Ali, 1996. *Management of Tank Irrigation by Government and Community: An Economic Analysis of Tank Performance in Tamilnadu,* Water Technology Center, TNAU, Coimbatore.

Rao,D.S.K, 1993. 'Groundwater Over-Exploitation Through Bore holes Technology', *Economic and Political Weekly,* Vol.38, December 25th.

Rosegrant, M. W. and C. Ringler (1999). *Impact of Food Security and Rural Development of Reallocating Water from Agriculture*. Washington D.C., International Food Policy Research Institute: 42.

Shah, T. (1993). *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy*. Bombay, Oxford University Press.

Singh, C. (1990). *Water Rights in India*. New Delhi, Indian Law Institute,.

Singh, C. (1991). *Water Rights and Principles of Water Resources Management*. Bombay, Indian Law Institute, N.M. Tripathi PVT. Ltd.

Vaidyanathan,A, 1996. 'Depletion of Groundwater: Some Issues', *Indian Journal of Agricultural Economics,* Vol51, Nos 1 and 2, Jan-June.

Vaidyanathan,A and Janakarajan,S, 1989. *'Management of Irrigation and Its Effect on Productivity Under Different Environmental and Technical Conditions'*, research report submitted to the Planning Commission, Government of India, MIDS, Chennai.

Vaidyanathan,A and Sivasubramanian,K 1998.

World Bank, M. o. W. R. (1998). *India - Water Resources Management Sector Review, Groundwater Regulation and Management Report*. Washington D.C., New Delhi, World Bank, Goverment of India.