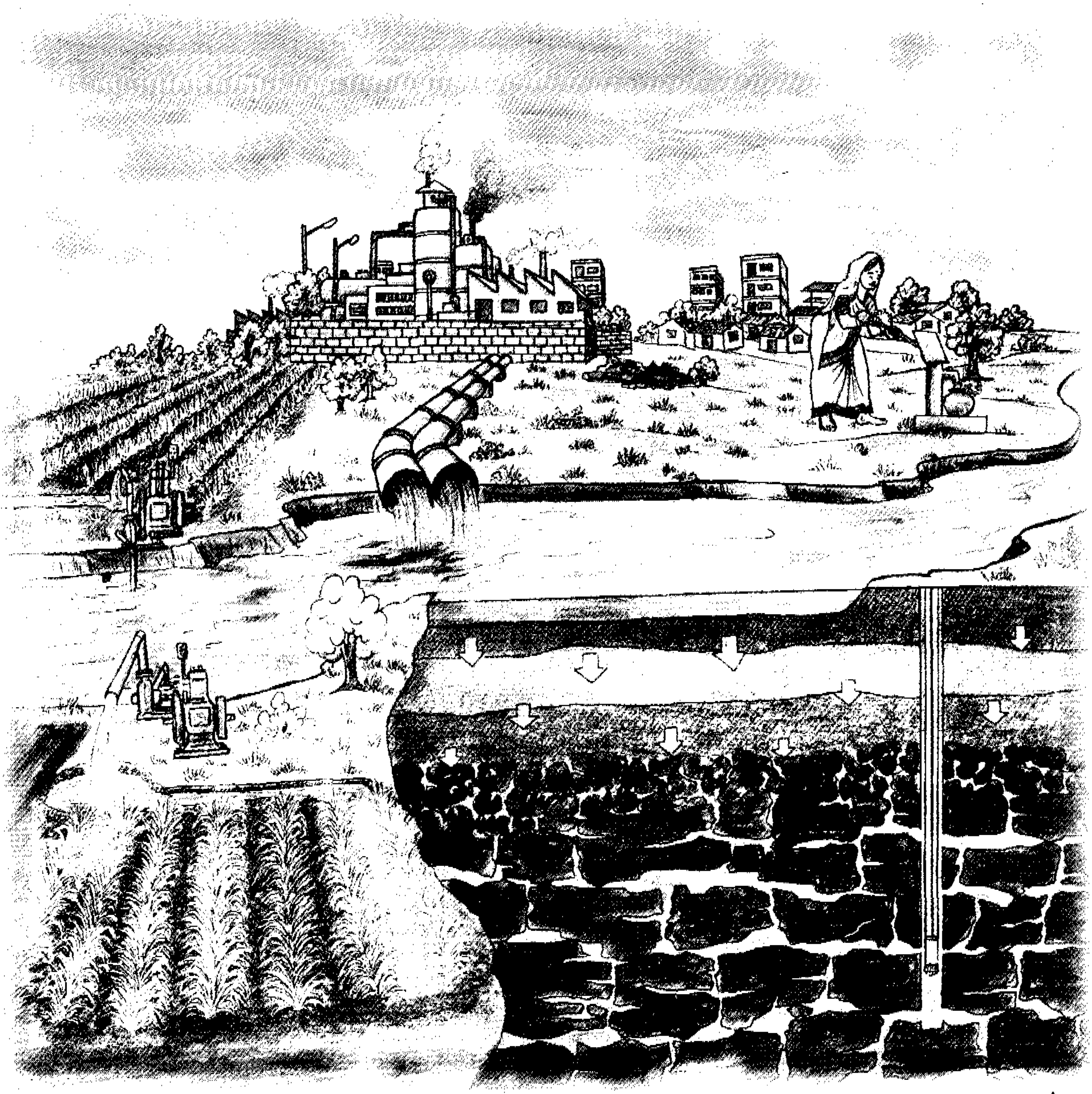
Groundwater Availability and Pollution

The Growing Debate over Resource Condition in India



Vikram Sarabhai Centre for Development Interaction - VIKSAT
Natural Heritage Institute

Selected Titles on Water from VIKSAT

1. **Local Water Management Initiatives: NGO Activities in Gujarat**; (Ed) Dr. Marcus Moench & M. Dinesh Kumar.(E).

2. **Proceedings of the Workshop on Water Management: India's Groundwater Challenge**; by Dr. Marcus Moench, Dr. Susan Turnquist & M. Dinesh Kumar.(E).

3. **Participatory Mapping As a Diagnostic Tool for Groundwater Studies**; by M. Dinesh Kumar, Praful J. Patel & Dr. Marcus Moench. (E).

4. **Groundwater Management: Role of Cropping Pattern & Irrigation Water Management**; by M. Dinesh Kumar & M.M. Chauhan. (E/G)

5. **Tube Well Turn Over: A Study of Groundwater Irrigation Organisations in Mehsana**; by M. Dinesh Kumar. (E/G).

6. **Groundwater Law: The Growing Debate**; (Ed) Marcus Moench.(E).

7. **Groundwater Management: Supply Dominated Focus of Traditional, NGO and Government Efforts;** (Ed) Dr. Marcus Moench. (E).

8. **Groundwater Availability & Pollution: Growing Debates Over Resource Condition in India**; (Ed) Dr. Marcus Moench.(E).

9. **Electricity Prices: A Tool for Groundwater Management in India?**; (Ed) Dr. Marcus Moench. (E)

10. **Groundwater Management: Future Options**; by M. Dinesh Kumar (G)

11. **Managing Common Pool Groundwater Resources: Identifying Management Regimes**; by M. Dinesh Kumar. (E)

12. **Social Reproduction Vs Economic Reproduction: A Study of Women's Role in Agriculture**; by M. Dinesh Kumar and Anjal Prakash. (E)

13 **Banking on Cooperation: A Study of Irrigation Management Institutions *in* Gujarat** by M. Dinesh Kumar, Shashikant Chopde & Anjal Prakash (E)

E = English   G = Gujarati

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FOREWORD

The problem of groundwater depletion is increasingly felt by everyone in more than one ways. The resultant scarcity and the deterioration of quality render it difficult to use water even for drinking in several parts of the country. For instance, most part of the Ramanathapuram district in Tamil Nadu suffers from salinity.

Added to this, demand from industries for water is met from groundwater sources leading to over draft conditions. While this excessive withdrawal brings to fore the deterioration in the quality of water, the used water is discharged as effluents from the industries which in turn affect soil, and surface and ground water sources. While aquifers of Mehsana in Gujarat are being tapped at 170% of its capacity, hundreds of tanneries in North Arcot district in Tamil Nadu have rendered several surface water and ground water sources unfit for human and animal consumption. Drinking water is transported in tankers and sold in some of the villages. Examples such as this are aplenty. Unless we make serious efforts to intervene, there may be permanent damage caused to the water sources, especially the ground water sources. Though the groundwater is categorised as replenishable, several times, excessive withdrawals over long periods leads to structural changes that are perhaps non-reversible.

VIKSAT facilitated debates on these issues at practical and policy levels in a Workshop titled Water Management: India's Groundwater Challenge held during December 14-16, 1993. The workshop was very successful in the sense that vast literature was presented and debated during the three days. This valuable literature was codified by VIKSAT in the form of a series of publications under various themes. The present volume **Groundwater Availability and Pollution** is one among them.

Most of these titles are out of stock, and some have been reprinted. This is the second reprint being published on demand.

We hope our publications including the present one will continue to facilitate meaningful debates leading to policy actions at various levels.your Comments and suggestions for improvement are most welcome.

Srinivas Mudrakartha
Director

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PREFACE

Marcus Moench
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All papers contained in this monograph were initially prepared for the **Workshop on Water Management: India's Groundwater Challenge,** held at VIKSAT in Gujarat on December 14-16, 1993. This monograph is the third in a series of five being produced based on the workshop papers.

Over the past decade, debates over the sustainability of groundwater use patterns have been slowly growing in many parts of India. In locations such as Mehsana District in Gujarat and Coimbatore District in Tamil Nadu, water tables are dropping and groundwater aquifers are being depleted. In other areas, groundwater pollution problems are becoming evident. Nationwide, as R.S. Saksena documents in this volume, the number of wells with electric or diesel powered pumps has grown dramatically since 1950. Figures recently produced by the Central Ground Water Board indicate that nationwide the number of wells has grown from 3,865,400 in 1950-51 to 15,566,600 in 1991-92 and the number of diesel and electric pumps from 87,000 to 13,921,000 over the same period.[1] Installation of wells and pumps has been and continues to be virtually unregulated. Pollution is also recognised as a concern. The Central Pollution Control Board is now initiating activities in 22 sites which have been identified as critically polluted (Biswas *et al.* this volume). Nationwide, industrial activities have grown greatly since Independence. With economic liberalisation, these can be expected to grow still more rapidly over the coming decades. Urban areas are also increasing in size and with them the potential for groundwater pollution from concentrated waste flows.

In the above context, logic suggests that over-development of the available resource will occur, particularly in sensitive areas. Evidence from areas such as the districts indicated above and the 22 polluted sites identified by the CPCB indicate that this has indeed happened. Debates now center on the extent of groundwater over-development and pollution problems, their implications for policies supporting further development, and their consequences both for agriculture and vulnerable populations.

As the papers in this monograph indicate, groundwater pollution has received far less attention than problems associated with falling water tables. This is not because groundwater pollution is a less serious concern than over-development -- over the long-term it may have far more serious implications for water availability -- but because data on the nature and extent of pollution are lacking. The Central Pollution Control Board is just initiating a first round of studies in areas which, on the basis of VIP and citizen complaints, are known to be critically polluted. With a network of only 480 sampling locations to cover the entire country, there is a

[1] Personal Communication, CGWB, 1995.

limited amount of baseline pollution data that can be collected (Biswas *et al.* this monograph). Furthermore, virtually all work has focused on point source pollution from industries and urban areas. With rapid growth in the use of fertilisers and pesticides, logic suggests that non-point source pollution from agricultural activities may pose a far greater threat to groundwater supplies. However persuasive logic may be, data on groundwater pollution are lacking and so debates tend to resolve little.

Where debates regarding over-development of groundwater resources are concerned, generally optimistic assessments of availability by the Central Ground Water Board and concerned state level departments are often in sharp contrast with evidence observed at a local scale. This division is very clear in the papers contained in this monograph. N. Kittu and T.S. Raju of the Central Ground Water Board present national overviews which, while acknowledging the presence of over-development in a few areas, emphasise official estimates that nationwide only 30% of the utilisable recharge is currently extracted. In contrast, local level studies by Wijdemans, Rao, Palanisami & Balasubramanian, Reddy and Kolavalli all document water level drops and emphasise the problems caused by over-development.

How extensive emerging groundwater over-development problems really are is a central question. Local case studies may not reflect common conditions. Many case study sites may, for example, have been selected on the basis of existing problems. The results may not, therefore, be representative of conditions existing over larger areas. On the other hand, groundwater recharge and extraction estimates done by the Central Ground Water Board or state level groundwater organisations are known to be unreliable. As R.S. Saksena, a retired Chief Engineer in the Ministry of Water Resources, discusses, current estimates of groundwater availability are of uncertain accuracy. In some areas where estimates suggest that extraction exceeds recharge, water tables are rising; in other areas estimates suggest plentiful resource availability but water tables are falling. Both the data on which estimates are based and the methodologies used for estimation need review, strengthening and possibly replacement. This is recognised in the paper by Kittu of the Central Ground Water Board. How it might be done and the relationship between data and user needs are discussed in the paper by Moench.

Although the extent of emerging groundwater over-development problems remains undocumented, their significance for agriculture, vulnerable populations and even drinking water supply is well documented in the case studies. Kolavalli, Palanisami & Balasubramanian and Rao clearly document the economic cost of falling water tables within their study areas. Where groundwater levels are falling, farmers must bear the regular costs of well deepening, lost investment in wells that go out of production and increasing risk of failure in the construction of new wells. Those who are unable to afford these costs lose direct access to groundwater and, in areas where groundwater markets do not exist or are imperfect (a common situation), may lose access to all irrigation water supplies. As a result, falling water tables tend to progressively exclude access for vulnerable groups to groundwater resources. The implications can, however, extend beyond equity. Palanisami & Balasubramanian document the stagnation in well irrigated area that has occurred over the past thirty years in Coimbatore

District of Tamil Nadu despite a doubling in well numbers. There, the average area irrigated by each well has declined from 1.56 ha in 1960-61 to 0.747 ha in 1990-91. Similarly, the concise report by Wijdemans documents the impact of agricultural pumping on water availability for drinking supply systems in northern Gujarat. There, agricultural pumping is causing average drops in the water table of 2-3 metres per year and water quality is declining. The competition between agriculture and drinking needs over scarce available water supplies is clear.

Different authors advocate different sets of responses to emerging groundwater problems. The Central Ground Water Board advocates the establishment of centralised regulatory systems to control groundwater extraction. The CGWB has circulated a model bill to the States that, if passed by the state legislatures, would establish this. Legal and operational frameworks that establish effective control over irrigation pumping are also seen as important by Wijdemans if drinking water sources are to be protected. In contrast, Rao and Palanisami & Balasubramanian suggest, as an alternative to comprehensive regulation, that over-development be addressed through a combination of power pricing incentives, the extension of efficient end-use technologies (such as drip) and limited regulation of well spacing. Finally, Kolavalli views improvements in water harvesting techniques, dryland farming and non-agriculture based job creation as the most viable response. Overall, however, effective avenues for addressing the range of pollution and over-development problems now emerging remain unidentified. None of the approaches proposed has been implemented or tested under Indian conditions. The identification of groundwater management approaches that are both effective in addressing pollution and over-development problems and are equitable is a critical area for future work.

GROUNDWATER QUALITY IN CRITICALLY POLLUTED AREAS - A PROJECT OF CPCB

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Abstract

With increasing reports of water pollution in surface aquatic resources, particularly in rivers due to indiscriminate discharge of both municipal sewage and industrial effluents, the significance of maintaining good groundwater quality acquires prime importance. Until recently, demands for groundwater have primarily been from domestic and agricultural sectors. Of late, with industrialisation increasing, demand from this sector is growing, further increasing pressure on the limited available groundwater resources.

The Ministry of Environment and Forests (MEF) has been receiving complaints regarding poor groundwater quality from the public in the vicinity of industrial areas. In this connection, the MEF directed CPCB to conduct surveys in 22 sites identified as critically polluted including Visakapatnam (A.P.), Vapi (Gujarat), Korba (M.P.), Angul-Talcher (Orissa), Manali (T.N.) and Durgapur (W.B.). These surveys focused on ambient air, water and groundwater quality. The surveys confirmed poor groundwater quality in most of the areas. Following this, a project to monitor groundwater quality in these polluted areas was proposed. Through this project groundwater samples shall be analysed for physio-chemical, bacteriological and heavy metal contamination. The project will commence in January, 1994 and will be executed by the Ground Water Boards and Pollution Control Boards.

1.1 INTRODUCTION TO CENTRAL POLLUTION CONTROL BOARD (CPCB)

The CPCB under the Ministry of Environment & Forests was constituted in September 1974 under the Water (Prevention & Control of Pollution) Act, 1974. Initially its mandate focused only on water pollution. Since May 1981, the CPCB has been entrusted with the added responsibility of air pollution control under the provisions of the Air (Prevention & Control of Pollution) Act, 1981. Enactment of the Environment (Protection) Act 1986 further widened the scope of activities of the Board.

The functions of the Board relating to water pollution consist of collecting, compiling and publishing technical and statistical data relating to water pollution and the measures devised for its effective prevention, control or abatement.

[2] Respectively: Chairman, and Environmental Engineer

1.2 WATER QUALITY MONITORING

The preamble of the Water Act stresses the objective of maintaining or restoring the wholesomeness of water quality. It was therefore imperative to establish a national water quality monitoring network. This was designed to monitor water quality status in relation to designated best uses that the CPCB had identified for specific river stretches. The CPCB had come out in 1985 with a River Basin Atlas demarcating designated best use of stretches in the major river basins (individual catchment areas equal to or greater than 20,000 sq km) based on primary water quality criteria (pH, dissolved oxygen, biochemical oxygen demand and total coliform).

As of 31st March 1993, the CPCB has a network of 480 sampling locations in different states. These are monitored by the State Pollution Control Boards (SPCBs). The water quality network focuses pre-dominantly on surface water quality. It covers primarily major and medium rivers in the country along with some creeks, drains and lakes. The existing water quality network is being monitored under three major programmes:

(a) Monitoring of Inland National Aquatic Resources (MINARS)
(b) Global Environmental Monitoring Systems (GEMS/WHO)
(c) Ganga Action Plan (GAP)

The monitoring of groundwater quality constitutes a very minor proportion of the CPCB water quality monitoring network.

1.3 CRITICALLY POLLUTED AREAS

The CPCB, in consultation with the SPCBs, has identified 22 critically polluted areas in the country to focus its efforts on. The goal has been to demonstrate that concerted efforts can lead to abatement of pollution and thus improve the overall environmental quality (air, water & groundwater quality). The polluted areas were identified based on repeated public and VIP complaints and recommendations from the concerned SPCBs. The Statewise distribution of these areas are as follows:

	State	Area
1.	A.P.	Visakapatnam, Patancheru-Bolaram
2.	Assam	Digboi
3.	Bihar	Dhanbad
4.	Delhi	Najafgarh Drain Basin Area
5.	Gujarat	Vapi
6.	H.P.	Parwanoo, Kal Amb.
7.	Karnataka	Bhadravathi
8.	Kerala	Greater Cochin
9.	Maharashtra	Chembur

10.	M.P.	Korba, Ratlam-Nagda
11.	Orissa	Angul Talcher
12.	Punjab	Govindgarh
13.	Rajasthan	Pali, Jodhpur
14.	T.N.	Manali, North Arcot
15.	U.P.	Singrauli
16.	W. Bengal	Durgapur, Howrah

The CPCB in coordination with the concerned SPCBs organised detailed investigative surveys on sources of pollution for almost all the identified abovementioned areas. These investigations assisted in preparing action plans for implementing pollution control measures particularly with respect to ambient air quality, municipal sewage and industrial effluent. The investigations conducted in the polluted areas also covered groundwater quality. The reports do indicate critical groundwater quality problems in most of the identified polluted areas.

1.4 GROUNDWATER QUALITY IN POLLUTED AREAS

According to the detailed survey reports available at the CPCB, the following are salient features bearing on groundwater quality in the identified problem areas:

1.4.1 Vapi (Gujarat)

This is a major industrial area containing a variety of chemical (organic & inorganic), pesticides, pharmaceuticals and dye industries. It is referred to as the GIDC Vapi Industrial Estate. The major water source is the river Damanganga. Although the surveys do not cover groundwater quality, the analysis of surface water quality indicates the presence of pesticides. This warrants vigilance on the groundwater quality due to the persistent nature of pesticides.

1.4.2 North Arcot (TN)

North Arcot is in the Palar river basin. The meager water supply of the basin (rainfed) forces the area to depend on groundwater. The groundwater monitoring results indicate the presence of chromium concentrations exceeding permissible limits. This could be attributed to wastewater from tanneries. Tanneries are a major industrial activity in this region.

1.4.3 Korba (MP)

Korba is in Bilaspur District, a rich coal reserve area containing major industrial activity in addition to mining and thermal power plants. The Hasdeo river in this area is the main source for drinking and industrial activity. Groundwater quality analyses at selected locations indicate high zinc, iron, fluoride and microbial activity.

1.4.4 Singrauli (UP)

Singrauli contains large coal reserves along with major industries such as HINDALCO, Kanoria Chemicals and thermal power units. The Rihand Reservoir is the main water source for the area. Groundwater quality analysis done in the industrial area of Annapara Colony and Renukoot indicate high fluoride, chromium and iron, exceeding Bureau of Indian Standards limits.

1.4.5 Greater Cochin

The major source of water for all purposes in this area is the Periyar river. The major industrial units are fertilisers, pesticides, chlor-alkali and chemical industries. Groundwater quality analyses conducted at 10 locations within the industrial vicinity indicate acidity, heavy metals, pesticides, fluoride and iron problems.

1.4.6 Manali (TN)

Groundwater is the principal source for domestic industrial and irrigation activity in the Manali industrial area where the major industries include ETD Parry, Madras Refineries and the Ennore Power Station. The groundwater quality analysis conducted at 10 locations indicate the presence of microbial activity, sodium, fluoride and nitrate.

1.4.7 Visakapatnam (AP)

The main sources of water are the Meghadrigedda river and groundwater. The industrial area has large units including FCT Coromandal Fertilizers, Hindustan Zinc, & Hindustan Petroleum. Groundwater quality analyses at 5 locations indicate heavy metals, fluoride and nitrate problems.

1.4.8 Pali (Rajasthan)

Groundwater quality samples collected at 17 locations along the Bandi river up to 40 km downstream of Pali town indicated contaminated water unsuitable for agriculture. The area has several clusters of small scale textile industries.

1.4.9 Chembur (Maharashtra)

This is the most discussed area mainly with respect to air pollution from the fertiliser and petro-chemical industries. The survey report on the area does not discuss groundwater quality. Groundwater quality shall, however, be monitored in the future.

1.4.10 Dhanbad (Bihar)

This area has mostly air polluting industries such as coke oven plants in addition to fertiliser and chemical units. Groundwater samples collected at 2 locations indicate high TDS, nitrate and conductivity. As a result, groundwater quality needs to be monitored for the wells near the Damodar river.

1.4.11 Talcher-Angul (Orissa)

The Brahmani river is the main source of water for this industrial area which contains fertiliser units, NALCO and thermal power stations. Groundwater quality analysis done at 15 locations indicates the presence of heavy metals, fluoride and microbial activity.

1.4.12 Bhadravati (Karnataka)

The Bhadra river is the main source of water for domestic and industrial activity in this industrial steel town. Although no groundwater quality pollution studies were done, the potential for groundwater pollution cannot be ruled out.

1.4.13 Gobindgarh (Punjab)

Groundwater is the main source of water supply in this area of steel and re-rolling mills which cause air pollution. The groundwater quality analysis done at 6 locations indicates high microbial activity.

1.4.14 Bolaram - Patancheru (AP)

Groundwater is the principal source for domestic consumption. The groundwater quality analysis done at 15 locations reports most of them unfit for domestic consumption. The major industrial units are pesticides & pharmaceuticals.

1.4.15 Howrah & Durgapur (WB)

Groundwater pollution has been noted in this area. The survey report is, however, still awaited from the concerned state agency.

1.4.16 Parwanoo & Kala Amb (HP)

No groundwater quality studies have been conducted in this area since most industries are air polluting by nature. The CPCB shall, however, monitor groundwater quality due to public response.

1.4.17 Jodhpur (Rajasthan)

The city of Jodhpur depends mostly on groundwater and rain harvesting. The rate of exploitation of groundwater has been given wide publicity and the city is facing acute water problems, hence groundwater quality merits attention.

1.4.18 Digboi (Assam)

Groundwater quality studies have not been done. However it is felt that the potential for groundwater pollution can not be ruled out.

1.4.19 Ratlam-Nagda (MP)

This industrial area depends largely on Chambal river as a source of water for domestic and industrial activity. The survey report is awaited.

1.4.20 Najafgarh Drain Basin Area (Delhi)

The CPCB H.O. had conducted two rounds of groundwater quality monitoring in 1981 and 1985 following an uproar in the Parliament regarding groundwater quality contamination with respect to cadmium (details and findings in CPCB publication PROBES/34/1985-86). Heavy metal was detected.

1.5 GROUNDWATER QUALITY MONITORING PROGRAMME

Pollution of groundwater arises mostly from percolation of polluted water from the surface and the resultant interaction between the water and the media of the aquifer. Looking into the parliament questions, and complaints on pollution from industrial wastewater seepage and the significance of groundwater being exploited more and more for domestic purposes in view of both the meager amount and un-potability of the surface water sources, it was important that CPCB also involved itself in groundwater sampling to supplement its on-going major surface water quality monitoring activities being executed under the MINARS & GEMS programmes.

Based on the groundwater quality investigations in the polluted areas and the response from the public to attend to the deteriorating groundwater quality in the polluted areas, the Ministry of Environment & Forests (ME & F) decided to execute a project in conducting groundwater quality monitoring in these identified critically polluted areas. The task of coordinating this project was assigned to CPCB.

The CPCB invited proposals from various agencies willing to participate in the programme and accordingly the polluted areas were assigned to them. Where no response was received (for example, in Calcutta, Kanpur and Vadodara) the CPCB assigned the task to its own staff. As can be recalled from the previous section the above areas are mainly industrial in character. As a result, the possibility of groundwater quality further deteriorating due to industrial effluent seepage cannot be ruled out.

1.6 THE GROUNDWATER QUALITY PROGRAMME SCHEDULE

The groundwater quality programme as envisaged at present commences in January 1994 and the entire project duration is for 12 calendar months initially. The executing agencies shall identify representative groundwater sampling locations, typical of each problem area and analyse samples for 24 water quality parameters. The parameters include heavy metals, pesticides, bacteriological parameters besides some physio-chemical parameters as per the Annexure.

The agencies that shall be participating in this programme are as follows :

1. Public Works Department Madras, Tamil Nadu
2. Ground Water Department, Jodhpur, Rajasthan
3. Orissa Lift Irrigation Corporation Ltd., Bhubaneshwar
4. Gujarat Pollution Control Board, Gandhinagar
5. H.P. Pollution Control Board, Shimla
6. CPCB, Zonal Office, Calcutta
7. CPCB, Zonal Office, Kanpur
8. CPCB, Zonal Office, Bangalore
9. CPCB, Zonal Office, Vadodara
10. CPCB, Head Office, Delhi.

The groundwater quality monitoring network is envisaged to have 134 groundwater sampling locations with a minimum of 4 upward depending on the gravity of the situation.

1.7 CONCLUSION

To plan the groundwater quality programme for individual polluted areas it is necessary to obtain hydro-geological information on the aquifer (water levels, hydraulic gradients, transmissivity and velocity of flow of water), use characteristics (industrial, agriculture and domestic), the magnitude of threats to water quality, and information on existing and potential influences on groundwater quality and details of land use. Undoubtedly it may not be possible to have all these information before initiating aquifer management actions. However this information once assembled along with the groundwater quality data information collected in the end of the project duration shall further assist in strengthening the course of future action.

STATUS OF GROUNDWATER DEVELOPMENT AND ITS IMPACT ON GROUNDWATER QUALITY - AN APPRAISAL

N. Kittu
Central Ground Water Board

Abstract

Groundwater, even though grouped under "Minor Irrigation", has been playing a "major role" in the irrigation sector in our country. It accounts for nearly 45% of the irrigation potential created. Furthermore, 87% of safe drinking water sources in rural areas depend on groundwater. Though status of groundwater development in the country as a whole is suboptimal, there are a few districts in the country where the resource is overexploited or reaching a critical stage of development. In these districts, adoption of suitable recharge measures is required for sustainable development. In contrast, in about 24% of the 424 districts in the country there is considerable scope for further development of groundwater. The Central Ground Water Board (the apex organisation for groundwater assessment, development and management in India) has been monitoring the groundwater situation, both level and quality, in time and space through a network of more than 16,000 observation wells. The present paper attempts to project the prevailing status of groundwater development, its quality and related data base, incorporating appropriate strategy for optimal development.

INTRODUCTION

The vital role of water resources in moulding the socioeconomic development of any nation is well known. In recent times demand for water especially groundwater has been increasing from domestic water supply, irrigation and industrial sectors due to inadequate availability of surface water and the advantages inherent with groundwater (e.g. dependability as a source, ease of rapid development, better quality, low capital costs and availability at the location desired). It is also a fact that groundwater is essentially a peoples' resource developed by people at large. Although the country has witnessed rapid progress in the development of groundwater in the past few decades, the inherent advantages in its development have resulted in a haphazard unplanned approach leading to the twin problems of groundwater depletion and quality deterioration. Added to these problems associated with rapid development are waterlogging and soil salinity problems caused by the unilateral development of surface water in major irrigation project command areas of the country. In the present paper an attempt is made to project the status of groundwater development and its overall impact on the environment.

GROUNDWATER RESOURCE - STATUS

It is well known that the occurrence and storage of groundwater is governed by three important factors namely geology, topography and climate in the form of precipitation. India is underlain by a wide spectrum of geological formations, ranging in age from the Archaean to Holocene. Apart from geology, there is wide variation in topographic settings and in the quantum and duration of rainfall (not only from season to season but also from region to region). Since rainfall constitutes the principal recharge of groundwater, its availability varies likewise. Nearly 40% of the country is classified as arid to semi-arid with an annual rainfall of 500-1000 mm. These areas are vulnerable to drought. In addition, approximately two-third of the country is underlain by fissured formations, popularly known as hard rocks, which are characterised by secondary porosity and permeability. In these formations groundwater availability varies widely depending upon, among other things, the depth and degree of weathering and depths and degree of fracturing. The aquifers have limited to moderate potential. Dug wells have been utilised from time immemorial in the hard-rock regions. These are now being supplemented by more modern technologies including dug cum bore and borewells sited based on better understanding and appreciation of fracture porosity and geometry and by the utilisation of remote sensing and geophysical techniques.

About one-third of India is underlain by alluvium and other sedimentary formations. These formations are characterised by primary intergranular porosity. Alluvial aquifers are regionally extensive with prolific yields of more than 150 cubic meters/h and capable of sustained development by heavy duty deep tubewells. In addition to deep tubewells, shallow tubewells, dug wells, cavity wells and filter points are other modes of development.

It must be understood that natural replenishment of groundwater is a slow process which takes place in a diffused manner. Both the Central Ground Water Board and various State Groundwater Organisations have been carrying out surveys and exploration at the macro and micro-level and have collected voluminous data on the occurrence of groundwater in different hydrogeological environs. This has resulted in the delineation of areas suitable for groundwater development, a better understanding of the nature of aquifers and their development potential and characterisation of the groundwater regime in terms of the amount of water present, its quality and how it varies both in time and space.

The replenishable groundwater resource in India has been assessed on the basis of the water table fluctuation method to be on the order of 43.18 Mha m. Fifteen percent of this (amounting to 7.09 Mha m) is reserved for drinking water supply, industrial use and other system losses. The remaining 85% of the resource (36.08 Mha m) is known as the utilisable resource and is earmarked for the irrigation sector. On January 1, 1990, the net draft was estimated to be 11.52 Mha m. The remaining potential available for further development was estimated to be 24.56 Mha m. Status of development was approximately 31.92% of the utilisable resource.

Although groundwater utilisation is a relatively small fraction of the available resource for the country as a whole, there are certain areas where groundwater development is quite considerable and in some cases the draft exceeds the annual utilisable recharge. A critical analysis of the status of development, districtwise, brings out the fact that out of 424 districts in the country, groundwater is grossly underutilised and development is less than 10% in 102 districts or 24% of the total districts. In contrast to the underutilisation, there are pockets in the country where groundwater is already in a state of overexploitation ranging from 100 - 260% of the utilisable potential. Thirteen districts spread in Punjab (5) Haryana (3) Rajasthan (2) Tamil Nadu (1) and Delhi States (2) fall under this category. A detailed examination of the blockwise status of development in the country as a whole brings out the following :

Status			**No. of blocks**	**%**
i)	Status of development less than 65% of the utilisable potential - "White category"	=	3950	86%
ii)	Status of development bet. 65-85% of the utilisable potential -"Grey category"	=	361	8%
iii)	Status of development more than 85% of the utilisable potential -"Dark" including overexploited" category	=	257	6%
	Total blocks in the country	=	4568	

In the case of Maharashtra State where groundwater assessment is being carried out on a watershed basis, the status of development is as given below:

Total number of watersheds = 1481 (spread over 366 blocks).

Number of watersheds under "white" category = 1390 or 94% of the total

Number of watersheds under "grey" category = 57 or 4% of the total

Number of watersheds under "dark" category = 36 or 2% of the total

Similarly, in the case of Gujarat State where groundwater assessment is carried out talukawise the present status is as follows :

Total no. of talukas = 183

Number of talukas under "white" category = 151 or 83% of the total

Number of talukas under"grey" category = 14 or 7% of the total

Number of talukas under "dark" category =18 or 10% of the total

STATUS OF GROUNDWATER BASED ON IRRIGATION POTENTIAL

Groundwater has come to be recognised as a sustainable resource for irrigation over the past few years. This is due to the availability of groundwater as a dependable source even in years of recurring drought/moisture stress such as the 1987 drought which affected large parts of the country. Groundwater now accounts for approximately 45% of the total irrigation potential in the country. The steady increase in groundwater irrigation potential from 6.5 million ha in 1951 to nearly 34.8 million ha in 1990 stands testimony to the "Major" role of groundwater in the irrigation sector though grouped under "Minor" Irrigation.

Similarly the proliferation of groundwater abstraction structures is phenomenal, thanks to the inbuilt incentives in the form of subsidies extended by Government to small/marginal farming community and also due to the massive institutional finance investment in groundwater (especially by NABARD) and to the large scale energisation programme of pumpsets by the Rural Electrification corporation. Remarkable progress has been registered in the construction of various groundwater abstraction structures from 1951 to 1990. In case of dug wells the increase is from 38.6 to 94.9 lakhs[3], shallow tubewells from 3000 to 47.54 lakhs and public tubewells (heavy duty tubewells) from 2400 to 63,600. Similarly the number of electric pumpsets have registered a steady increase from 21,000 to 87.66 lakhs and diesel pumpsets from 66,000 to 44.67 lakhs. In our country, the concept of irrigated agriculture has come to stay mainly due to groundwater as a source and irrigation has been extended from traditional food crops to more renumerative cash crops.

The Central Ground Water Board, the apex organisation at the national level for groundwater assessment, development and management has been continuously monitoring the overall situation of groundwater availability and its development including impact on quality and socio-economic conditions. This monitoring is undertaken through reappraisal hydrogeological surveys in areas registering abnormal fall/rise in water levels and areas having quality problems. A realistic picture, with regard to actual quantum of groundwater draft, is attempted through sample surveys all over the country. In addition, it is contemplated to set up a group of experts drawn from various organisations/institutions for reviewing and refining the 1984 guidelines of the "Groundwater Estimation Committee" which are now used to estimate recharge and extraction. This review will take into account the voluminous hydrogeological data generated in recent years in different parts of the country. The sole objective is to arrive at realistic estimation of the dynamic resource and balance for further development.

STATUS OF GROUNDWATER MONITORING AND RELATED DATA BASE

Monitoring of groundwater regime (water level and quality) was initiated by Geological Survey of India in 1969 with a low density of one well per degree sheet (1 well per 11600 sq

[3] Each "lakh" is equal to 100,000

km). From a humble figure of 410 monitoring wells in 1969, the network has gradually increased over the years. At present 15332 wells are monitored regularly by the Central Ground Water Board. Water levels are collected 4 times in a year in January, May, August and November. Water samples are collected once a year during the pre-monsoon period. In addition, the various State Groundwater organisations also monitor the groundwater regime. Depending on the state, data is collected on a basis which ranges from monthly to twice a year. The time duration of measurements is not uniform throughout the country. The States, in all, monitor more than 30,000 wells. Nearly 90% of the observation network consists of open dug wells.

As far as C.G.W.B. is concerned, well locations in the network are decided based on local conditions like areas showing decline/rise in water level, quality problem, etc.

A critical analysis of well hydrographs brings out the following:

i) Water level respond to monsoon rainfall and show a rise. However, there is a time lag in response. This rise is followed by a period of decline.

ii) Generally well hydrographs are characterised by a peak followed by a recession. The recession limb when critically analysed exhibits two slopes, one steep slope from August to October/November and gentler one from October/ November to June. Bulk of monsoon recharge representing steeper limb dissipates.

iii) Rate of recession of groundwater levels in case of alluvial formations is rather slow compared to quick rate of recession in hard rocks. Furthermore, the rate of recession is quite pronounced and fast in the beginning for about one to one and a half months immediately after peak. The bulk of this is lost as subsurface outflow since adequate soil moisture probably results in less demand for irrigation water.

iv) The amplitude of water table fluctuation and times of occurrence of inflection points are not uniform and vary from place to place depending upon the local hydrogeological set up, soil cover, quantum and duration of rainfall and draft characteristics. The above phenomena get further complicated in areas experiencing two monsoons (both southwest and northeast).

v) Fluctuation characteristics are more or less similar in areas with same hydrogeological environs.

Data from the monitoring network is mainly used for: (i) computing water level fluctuations (one of the important parameters for estimation of dynamic groundwater resources); (ii) finding out changes in status of groundwater storage so as to plan appropriate management measures in the form of augmentation of groundwater recharge in case of areas showing decline in water levels, or initiating vertical drainage measures in case of areas showing rise in water levels; (iii) monitoring changes in groundwater quality and related environmental aspects; (iv) evolving suitable strategy for development, management and protection of groundwater resources; and (v) predicting long term behaviour of the system.

Data from the monitoring network is also useful in analysing the long term trend of phreatic water levels. This was done for the decade 1981-90. Long term trends of pre-monsoon, post-monsoon and annual water levels representing both rise and fall of water level were computed through regression analysis and least square method. Based on this analysis, areas experiencing continuous decline/rise were delineated including zonation of the rise and fall values. Long term trends showing a rise or decline of up to 2 m are generally considered as "normal" fluctuations. While critically going through monitoring data a few anomalous situations have been encountered. One such instance is in areas with high stage of development which is not reflected in water levels in the sense there is no declining trend and vice versa. This situation is probably due to lack of sufficient control over observation wells to commensurate with the distribution and abstraction in the hard-rock medium that is highly heterogeneous and unisotropic in character.

The CGWB is engaged in in-depth analysis of the design and density of the existing network with a view to refining and optimising its coverage. For this purpose it is proposed to have more piezometers and piezometer nest in multi-aquifer system so that the monitoring wells reflect the true aquifer/phreatic/semi-confined/confined conditions under development. Provision is also kept for installation of automatic water level recorders in selected wells to get continuous data.

Keeping in view the ever increasing stress on the groundwater system and the need for good data to enable proper management of the resources, the National Monitoring Network will be integrated with network of various states and a uniform approach will be adopted with regard to selection of monitoring wells and frequency and duration of measurements. It is also contemplated to build up a data bank storage and retrieval system through networking of state and regional (CGWB) data bases with the main storage at CGWB headquarters.

GROUNDWATER QUALITY

Groundwater quality has assumed critical importance in view of increased threat of contamination from various point and non-point sources. Though less vulnerable to contamination when compared to surface water, groundwater pollution is becoming a major hazard. This is particularly relevant because groundwater accounts for 87% of the drinking water sources viewed as safe especially in rural areas. Hence groundwater protection becomes all the more essential. Groundwater quality varies widely depending upon the prevailing climate, physiography and geology in the country. In addition to this natural variation is the impact of human settlements on water quality.

The CGWB has collected valuable data on groundwater quality through sampling and analysis of monitoring network wells once a year during pre-monsoon, and sampling and analysis of selected wells in reappraisal surveys and exploratory wells. Based on the available data, broad aspects of groundwater quality formationwise and on a regional scale are summarised as below:

(i) The quality of groundwater in Precambrian formations is generally good. Electrical conductivity (EC) ranges from 500 - 2000 micromhom/cm at 25°C, though wide variations exist within the range. In high rainfall areas groundwater is generally fresh and soft with EC values less than 300 and chloride values less than 30 mg/l. In arid zones water quality is brackish with chloride values more than 1000 mg/l. Quality variations are large in consolidated sedimentaries of Pre-cambrian age. Groundwater is marginally hard with $CaCo3$ in the range of 200 - 400 mg/l. Brackish pockets occur in localised areas often in association with black cotton soils. In parts of Rajasthan EC values exceed 5000 micromhos/cm.

(ii) Quality of groundwater in Gondwana formations is generally potable and good except in areas bordering on Lathis in Rajasthan which have EC values of more than 3000 micromhos/cm and in the Panandharo area where trap covered sandstones show EC values exceeding 10,000 micromhos/cm.

(iii) Groundwater in the Deccan Traps is fresh with EC range of 300 - 1600 micromhos/cm and is of alkaline earth-bicarbonate type.

(iv) Tertiary formations are characterised by wide quality variations ranging from fresh to highly saline. Saline groundwater is common in parts of Rajasthan and coastal Saurashtra and Kutch. In northern parts of Kerala, coastal groundwater is brackish occasionally with hydrogen sulphide which may be due to leaching of salts in the intermingling clay layers during period of high sea level in the geological past.

Where location is concerned, groundwater quality is generally good in alluvial plains of the Ganga-Brahmaputra Valley and in Tarai-Bhabar zones. However, groundwater is appreciably mineralised in parts of Haryana, Punjab and Rajasthan due to the impact of extensive surface water irrigation. There is progressive degradation in quality of groundwater with depth in the western part of the Gujarat alluvial plains and southern part of Uttar Pradesh.

Coastal areas show large variations in water quality. In the Hooghly delta (West Bengal) groundwater at shallow depth is brackish and is underlain by freshwater. In the Mahanadi river delta, the reverse situation is common. Wide saline patches are common in the delta area between the Krishna and the Godavari rivers. The saline zone is comparatively narrow along the coast and further south in Tamil Nadu. In the west coast plain, groundwater is generally fresh even close to the coast except at a few localities. Large saline zones are encountered in the southern parts of Purna Basin with EC ranging between 2000 - 8000 micromhos/cm. In the Andaman and Lakshadweep islands, fresh groundwater occurs as a lens over saline zones at shallow depth. However, in areas away from coast groundwater is potable even at deeper levels as in the Andaman and Nicobar Islands.

In addition to salinity, other sources of natural contamination affect groundwater quality in some areas. Fluoride beyond the permissible limit of 1.5 mg/l is prevalent in nearly 8700 villages and affects drinking water supplies for nearly twenty five million people.

Although the source of fluoride is the underlying geological formations, the concentration in water is controlled by climate and the residence time of the water in the soil and phreatic zone. Generally fluoride is within permissible limits in high rainfall, high runoff and low evaporation areas. Fluoride is above permissible limits in arid/semi-arid tracts of Rajasthan, Punjab, Gujarat, Haryana, Uttar Pradesh, Andhra Pradesh and Karnataka. In some areas it is more than 10 - 20 mg/l.

Iron concentrations are often above the permissible limit of 0.3 mg/l in the Eastern and North-Eastern States. High concentrations of nitrate and potassium above the permissible limits of 45 mg/l are found in many locations and are mainly due to human and animal wastes and the high application of chemical fertilisers which is now prevalent in most parts of the country.

Groundwater quality is increasingly becoming vulnerable to pollution due to toxic chemicals in the vicinity of industrial areas and urban settlements as given below:

No.	Toxic Elements	Industries/ Industrial Town	Range in mg/l
1.	Chromium	Faridabad	0.1 - 35
	Copper,Nickel and Zinc	"	Above permissible limits
2.	Chromium	Ludhiana	12.9 (Chromium)
	Cyanide	"	2.0 (Cyanide)
3.	Fluoride, Zinc and Lead	Udaipur	Above desirable limits
4.	Chromium	Kanpur	Up to 27 mg/l
	Iron	"	Up to 1.7 mg/l
5.	Arsenic (naturally occurring in geological formation)	Parts of West Bengal	0.02 - 0.9 mg/l
6.	Low pH (due to effluents from galvanising)	Rairangpur, Mayurbhanj, Orissa	3.2 - 6.4 with mean of 5.4

In addition to the sites identified above, effluents from tanneries have contaminated heavily the quality of groundwater in parts of Tamil Nadu and Andhra Pradesh. Overexploitation of coastal aquifers in parts of Gujarat and Tamil Nadu has resulted in seawater ingress into freshwater aquifers rendering about 13,000 wells in 120 villages saline. Seawater/ freshwater interface is gradually advancing landwards 8 - 10 km inland along the Madras coast.

STRATEGY FOR OPTIMAL DEVELOPMENT

Based on the present availability and quality of groundwater resources, the following points emerge for consideration for which an appropriate follow up strategy has already been planned by the CGWB:

(i) By and large, barring a few select areas, stage of groundwater development in the entire country is on a low key. Keeping in view the underutilisation vis-a-vis a huge quantum of resources available in the Eastern and North-Eastern states a Centrally Sponsored Programme has been formulated accelerating the tempo of groundwater development through 5000 dugwells and 35,000 shallow tubewells. The scheme with a total financial outlay of Rs.67.75 crores is to be shared between Government of India and State Governments on a 50:50 basis and is in advanced stage of sanction. It will be implemented over a period of 5 years in the States of Bihar, West Bengal and Orissa in the first phase.

(ii) CGWB is fully seised of the problems of dark and overexploited areas. It is pertinent to mention that a dark block need not necessarily mean overdevelopment. However, in certain identified areas, suitable programme for augmenting groundwater recharge through artificial recharge measures have already been initiated. In the first phase, under a central sector scheme, the states of Maharashtra, Karnataka, the Union Territory of Chandigarh and the State of Delhi have been covered under artificial recharge programmes. In addition, there is also a centrally sponsored scheme for implementing various artificial recharge techniques (duly taking into account the relevant hydrogeological set up, nature of soil cover, availability of source water, its quality and appropriateness to local conditions) in the overexploited and dark blocks in the entire country in the first phase.

(iii) In select major command areas experiencing waterlogging and soil salinisation, studies are underway for finding out the feasibility for conjunctive use of both surface and ground waters for optimal development.

(iv) Keeping in view the increasing vulnerability of groundwater to pollution from various sources, CGWB through its Pollution Directorate and Central Chemical Laboratory has been guiding and coordinating pollution studies being carried out by the Regional Directorates in selected industrial zones in the country. The main emphasis of the studies is laid not only in identifying the source of pollution but also in understanding the flow mechanism and migration of pollutants, so as to plan effective preventive and remedial measures. Further, as a first step in this direction, preparation of groundwater quality map of the entire country is under progress.

(v) Strengthening of the infrastructure for proper storage and retrieval of data base on groundwater resource potential, monitoring and quality is an ongoing process envisaging linkage of Regional and State level Data Storage System with the National Groundwater Storage and Retrieval System.

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ACCESS TO GROUNDWATER: A HARD-ROCK PERSPECTIVE

Shashi Kolavalli
L.K. Atheeq[4]

Abstract

Groundwater markets have emerged in various parts of India. The authors argue that these markets promote efficient and equitable groundwater use, particularly in areas of water abundance. On the other hand, in areas of water scarcity they may lead to unsustainable withdrawals or to inequitable access to groundwater. Clearly, markets operate differently under different aquifer and ecological conditions. The authors carried out research to identify characteristics of groundwater utilisation through the functioning of markets for irrigation services in a hard-rock area of south India. Hard-rock areas, which characterise the bulk of India's geographical regions, generally have limited groundwater supplies.

The paper provides substantial data from a case study of two villages in Karnataka. These data show that in hard-rock areas pressure is put on groundwater for irrigation if rainfall is inadequate, if surface irrigation is unavailable, and if commercialisation of agriculture is spurred by access to markets particularly for vegetables and fruits. In the case study site this led to extraction rates which exceeded recharge, resulting in an increasing failure rate for open wells and a consequent need to drill and equip tubewells. Significantly, one in three efforts to drill a productive well fail. The well failure rate increases the average cost of a successful well by an estimated Rs. 12,500, raising the total cost of a hard-rock well to about Rs. 62,500. This compares to about Rs. 12,000 for a well in an unconsolidated aquifer area, and puts wells far out of reach for many farmers who cannot gain access to credit or for whom the risk of failure is too high.

The water market in these villages was limited and in general did not provide access to water for non-well-owners. Surplus water was limited, after well-owners had taken what they could most profitably utilise. Nearly all well-owners sold to only one buyer, most often another well-owner. Most buyers were also well-owners, meaning that marginal and most small farmers, who have no wells, have no access to water through irrigation services. High returns on larger (i.e. irrigated) farms continue to increase disparity, but also continue to provide a strong incentive for those with sufficient resources to invest in more wells. Payment for irrigation services varied, and were often linked with exchange of other inputs such as labour, land or credit.

The authors suggest that farmers are averse to jointly-owned tubewells as they involve too much uncertainty and high potential for conflict. Yet the externalities possible when

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groundwater is privately exploited seem inevitably to lead to unsustainable extraction rates. If neither joint nor private tubewells are feasible, how then may groundwater be managed? The authors submit that the only hope for those without access is improvement in water harvesting and dry farming techniques themselves. Yet they interpret their data to imply that agriculture without irrigation simply cannot sustain even farmers who own their own land.

INTRODUCTION

Equity in access to groundwater is of concern as groundwater offers considerable potential to enhance land productivity. When combined with inequity in landholdings, unequal access to groundwater has the potential to widen disparities in rural India [ODI 1980]. Given the prevailing property rights to groundwater which give the right to water to whoever captures it, groundwater can be exploited both privately and publicly. Private wells could be owned either individually or collectively by a few individuals or cooperatives. Individual ownership, however, is most common. An institution that has emerged along with private exploitation of groundwater is the market for irrigation services in which well-owners supply irrigation services to their neighbours. Market here refers to, as defined by Bardhan (1988, p.157), any transaction based primarily on economic principles.

The market for irrigation services is an institution which provides wide access to groundwater to those who do not own wells just as public tubewells do. The 1975-76 fertiliser demand survey indicates that renting of pumpsets was prevalent in most parts of the country (Saleth 1992, p.2). The functioning of the market has the potential to yield both efficiency and equity benefits. A market for irrigation services can lead to higher efficiency by enabling i) reallocation of water among farmers to those who can put it to better use and ii) higher well capacity utilisation by those whose landholdings are smaller than the area their wells and extraction mechanisms are capable of irrigating. Groundwater irrigation service markets can also promote equity by extending the benefits of groundwater use to non-well-owners. The benefits to non-well-owners include i) higher and more risk free incomes from groundwater irrigation, ii) appreciation in the value of their lands because of access to irrigation, and iii) improved wages and employment arising from irrigated agriculture for the workers (Shah 1991, p.336).

As the primary objective of public tubewells is to provide access to small and marginal farmers who cannot afford a well of their own, the market for irrigation services offers an alternative to public tubewells. The market is superior to public tubewells as it is more decentralised, calls for minimal public investments (except for provision of infrastructure) and does not entail problems generally associated with the management of public investments. The users often find the services to be better than private tubewells and the markets for irrigation services flourish even in the commands of public tubewells (Kolavalli and Shah 1992, Pant 1992). The users therefore show a higher willingness to pay for irrigation services in the private market than for services from publicly managed surface andgroundwater irrigation systems.

The criteria for assessing the functioning of the market as an institution to utilise groundwater could be those listed as goals of groundwater policy by Shah: efficiency, equity and sustainability (1993, p.1). Efficiency in groundwater use relates to the use of both capital structure built to extract groundwater and the extracted water. The market does lead to a more efficient utilisation of wells and the extracted water. Markets for irrigation services enable even small landholders to make investments in wells which would otherwise have been indivisible and beyond their capacity. Well-owners with small landholdings can achieve better capacity utilisation through sales. Water purchased in the market is also likely to be used more efficiently as the charges are often related to quantity used and are closer to true costs than in public irrigation systems. There is some evidence that water buyers in fact use water more carefully than well-owners; they combine irrigation with higher levels of fertiliser application compared to well-owners (Dhawan and Satyasai 1988). Where markets are well developed, the access to small farmers can be fairly high even with choice as to who they buy from (Shah 1993). Markets have the potential to leave both well-owners and their buyers better off. Particularly where water is abundant and, therefore, entry is relatively easy, market can be a very useful mechanism for providing access (Kolavalli and Atheeq 1990, p.62). But markets may not lead to sustainable use under some conditions. The incentive to extract a fugitive resource such as water even in excess of sustainable levels will be much stronger in the presence of a market.

The emergence of markets and their development, therefore, is of considerable interest. Essential conditions which facilitate the emergence of market can be classified as being related to supply and demand for irrigation services. Shah states that "availability of water resources, scale and quality of adoption of irrigated farming technologies, progress of rural electrification, quality of power supply and extent of land fragmentation are some of the factors which seem to influence the pace of development of water markets (Shah 1991, p.338). The necessary condition for supply of irrigation services is the presence of aquifers which lead to well yields in excess of owner's requirements or well yields which make well investments viable if one is to invest only to sell irrigation services. In addition, a reliable power supply, available particularly at a fixed cost, can further encourage supply of irrigation services. Irrigated agriculture viable at prices which can make supply of irrigation services remunerative combined with fragmented landholdings which discourage individual ownership create the necessary demand conditions for the emergence of a market for irrigation services.

Because of supply limitations, market exchange may be sparse in 'water scarce' regions. Groundwater endowment relative to land is inadequate in India, particularly in the hard-rock regions, which constitute the bulk of the geographical area but account for only a small proportion of utilisable groundwater (Dhawan 1986). Groundwater available is sufficient to irrigate only a small fraction of land in hard-rock regions. The extent and intensity of irrigation is heavily dependent on well yields and power availability. Hard-rock areas have consolidated formations which are characterised by layers of hard-rock between which the aquifer beds are embedded. Most parts of the country, including almost the entire Deccan plateau, consist of such formations. Water availability in such formations is scarce and uncertain in terms of depth of occurrence and magnitude. In hard-rock areas where water supply is limited, water availability can become a major constraint to market emergence. But markets do develop in water-scarce areas where irrigated agriculture is practiced using modern technologies. Some of the examples are Mehsana, Sabarkanta, Banaskantha and several water-scarce areas of Saurashtra region of Gujarat and Madurai district in Tamil Nadu (Shah 1991, p.338).

Scarcity, as is generally used in regard to groundwater, can take several forms. Groundwater scarcity can be reflected by one or more of the following: i) depth at which water is available, ii) yield at a given depth, iii) probability of well failure, and finally iv) water quality which can be a dimension of yield itself. Average extraction cost per unit of water is a fairly good indicator of scarcity. An increase in depth to water table and probability of well failure and a decrease in well yield can increase average costs. Scarcity and increases in true average costs may be concealed by subsidies and tariff structures in India.

In hard-rock conditions groundwater scarcity manifests itself in the form of all the three indicators: increased depth to water table, reduced yields and increased probability of well failure. Under these conditions, supply of irrigation services itself may become the major barrier to emergence of markets. Water exchanges will be limited as well-owners may not have any 'surplus' to sell, that is water available for pumping will be less than owners' needs for irrigating their fields.

However, market exchanges are not restricted to 'surplus' water only. The well-owners have a choice between using available water to irrigate their fields or selling it to their neighbours depending on the relative returns from doing so. There may be situations where it is more remunerative for the owner to sell than irrigate his/her fields. Many farmers situated in the vicinity of Coimbatore who are reported to sell water to residences without municipal water supply are putting water to a use which brings them higher returns (In this case, water is being allocated to non-agricultural use). The choice of sales over irrigation of one's own field entails a willingness to pay for irrigation services which is higher than what the seller can earn on his fields.

Poor well yields, which give small surpluses, combined with high returns from irrigation which cannot be matched by willingness to pay for irrigation services hinder water exchanges. Poor and uncertain well yields combined with uncertain electric supply also seem to make contracts between buyers and sellers more difficult to develop and enforce. The market for irrigation services, the functioning of which does not necessarily lead to inequity in relatively water abundant areas, may fail to emerge or may remain thin in areas where there is relative scarcity reflected by high average costs. Inequity may increase as a result of access to groundwater being restricted to well-owners. Even among the well-owners, the richer farmers may gain greater access compared to others by employing better extraction technologies. Externalities in the form of water withdrawals by one affecting water availability for others will also be far more frequent under these conditions.

STUDY SITE AND DATA

As part of a larger study on groundwater utilisation, particularly through the functioning of markets for irrigation services and under different aquifer and ecological conditions, a survey was conducted in two villages in Bangalore district, Karnataka. A site was chosen in Karnataka as nearly 97 percent of the area in the state has hard-rock aquifers (Dhawan, p.2). Only about 17 percent of the net sown area was irrigated in 1983-84. Bangalore is one of the districts where groundwater exploitation is extensive for garden farming as in other districts such as Tumkur and Kolar which are located close to the metropolitan area. Doddaballapur taluka in which the two study villages are located had nearly 2,750 wells in 1975 (GOK 1975). Though one of the major interests of the study was water markets, specific efforts were not made to select villages based on the functioning of the market. We presumed that water exchange would be prevalent wherever there is significant use of groundwater for irrigation.

Climatic conditions in the study village are semi-arid. The average rainfall is nearly 800 mm. The rainfall pattern in Bangalore city is fairly representative of the conditions in these villages. The rainfall at Bangalore averages about 825 mm. The rainfall, however, is not dependable. A rainfall which occurs with a probability greater than 0.75 or 75% is considered to be dependable (Seagraves in Virmani et al., p.9). Initial probabilities of rainfall being above 5 mm at Bangalore are close to 0.7 only in about 10 weeks during the rainy season (Virmani et al. 1983, p.32-33).

Timmasandra and Rajghatta, the two villages chosen for the study, are located 1 km. apart about 15 km. from Doddaballapur town. The conditions in the villages in terms of land quality, cropping pattern, rainfall and irrigation are similar. Agriculture is largely rainfed. Ragi, a millet consumed locally, is the major crop occupying more than half of cropped area. Most of the cropped area is cultivated in kharif using southwest monsoon showers. Some area is cultivated in rabi without irrigation using residual moisture and north and eastern monsoon showers. Summer crops are raised only if irrigation is available.

Groundwater is the chief source of irrigation in the villages. Two tanks in the villages provide irrigation to some extent. The tank in Rajghatta is not used for irrigation as it is heavily silted. The Timmasandra tank provides irrigation water mostly in kharif. Paddy is the major crop in the tank's command area. As a result of lack of perennial irrigation facilities, the cropping intensity in the villages is close to 100 percent.

Geological formations in Doddaballapur taluka are granitic gneisses. The depth to water table ranges from 1.6 to 20.8 metres. The depth of borewells range from 55 to 110 metres. The yields of dug wells range from 25 to 35 m^3 per day while that of borewells range from negligible to 38 m^3 per day (CGWB 1992, Annexure 3).

Households with and without wells were picked randomly from the population of households in the two villages. Though sampling was done separately, the samples from two villages have been pooled for analysis. The two villages contained 411 cultivator households, of which 79 households owned at least one well (Table 1).

Table 1. Sampling of Households for the Study

Villages	Number in		Number of Households	
		All	With Well	Without Well
Timmasandra	Population	159	33	126
	Sample	52	33	19
Rajghatta	Population	252	46	206
	Sample	58	22	36
Combined	Population	411	79	332
	Sample	110	55	55
	Percentage	26.76	69.62	16.57

Well ownership status and landholding were used as the basis for stratification. Of the 411 cultivating households in the two villages, 108 were selected, 55 of whom were well-owning households. A smaller sample was taken from the population of households without wells. The objective was to limit the total sample to about 100 households from which data could be collected by a single researcher. We wanted at least about 50 households with wells to be able to get reasonably accurate information on well operation. The reason for restricting data collection to two villages was to improve the chances of collecting reliable data. A graduate student working on his Master's thesis was engaged for data collection. One hundred households appeared to be a reasonable number to collect data from within the two to three months which were available.

Nearly one-half of the cultivating households in Timmasandra and 61 percent in Rajghatta were marginal farmers owning less than one hectare of land (Annex: Table 1). The proportion of households owning land between 1 to 2 ha was 18% and 16% in the two villages respectively. In Timmasandra, large farmers owning more than 4 ha were higher in proportion (16.35%) compared to Rajghatta (5%). The landholding composition of households in the sample is different from that of the population; marginal farmers are under-represented and the proportion of large farmers in the sample is much greater than it is in the population. The difference is due to some mismatch between official village records and actual landholdings: many farmers in the sample had holdings larger than what official records indicated. The primary reason is because a larger proportion of the well-owning households were included in the sample and they account for the bulk of the households with larger holdings in the villages.

Operated area and owned area of the sample households were not very different, indicating that most of the operated land was owned and very little land was leased in or out. Two kinds of land tenure arrangements were reported among the sample households: crop sharing arrangements and fixed rent contracts. Only 6 households out of 108 leased in some land. The number of households leasing out land was equally small at 4. All the households who leased out land were well-owners or medium and large farmers (according to farm size) and of those who leased in 3 were well-owners and the other 3 were households without wells. The total net leased in, defined as leased in minus leased out, was 0.14 ha.

WELLS AND WATER AVAILABILITY

There has been a rapid expansion in groundwater use in the two villages over the years. The number of wells in use increased from 7 in 1960 to 22 in 1970 and 72 in 1990. Thirty percent of the wells in the village were built in the short period between 1986 and 1990. This expansion in the number of wells has affected water availability. The level of water table has gone down significantly. The depth to which wells are constructed to tap water increased from an average of 46 metres in 1984 to 79 metres in 1990. As the water tables have gone down, there has been a total shift in the type of wells constructed. The last open well (OW) in the village was constructed in 1984. The average depth of dug wells in the village is about 10 metres compared to 60 metres for tubewells (TW) which make up the bulk of the wells built in recent years.

The sample containing 55 households included 72 wells nearly one-half of which were TWs. Their depth ranged from 24 metres to 106 metres. As stated above, depth of TWs which are the only types of wells constructed in recent years is considerably more than that of OWs (Table 2).

All the wells in the sample were fitted with pumps, all but one electric. OWs and dug-cum-bore (DCB) wells were fitted with 3 to 4 HP motors while TWs were fitted with 5 HP motors (Annex: Table 2). Most well-owners also invested in distribution systems. Distribution system consisted of PVC pipes buried underground or laid overground to be

Table 2. Salient Features of Wells

Items	Well Type		
	OW	DCB	TW
Number of wells	23	14	35
Well depth (m)	11	8	60
Diameter (m)	9	8	NA
Depth of Bore (m)	NA	25	NA
Casing length (m)	NA	6	21
Discharge (m^3/hr)	0	0	15
H.P. of motor	3.7	3.3	4.9
Distribution pipe length (m)	158	106	531
Pond area (m^2)	14	50	138

NA: Not applicable

moved as required. The average length of distribution system of TWs was nearly 500 metres. Because of unreliable and rationed electricity supply, many well-owners had constructed small ponds to store water whenever electricity became available. Twenty-three of the 35 TWs and 5 OWs or DCBs had such storage ponds. The average area of these ponds was about 140 sq. metres. They pumped water into these ponds mostly at night for use during days.

Discharges from TWs are better known compared to other types of wells as they are measured soon after construction. TW water yields ranged from 3 to 36 m^3 per hour. The average was about 15 m^3 per hour (3,000 gallons per hour). There was no relation between depth and yield among the 35 TWs in the sample. In OWs, water was available for about 10 hours per day during kharif and rabi, and for only about two and a half hours during summers. DCBs, on the other hand, permitted pumping for about 5 hours per day during summers though water availability was less than those of OWs during the other two seasons.

In hard-rock areas, the likelihood of striking water by constructing a well is not as high as it is in unconsolidated aquifers. As the location of a well is an important consideration in determining water availability in a well, gross measures of water availability and exploitation and net availability of water for utilisation in a region are not clear indicators of individual incentives to invest in groundwater exploitation. The overall availability in a geographical area is no indicator of the yield to be expected in a particular well. In addition, groundwater potential is dynamic as it depends on surface irrigation and the extent to which rainfall is harvested (Dhawan 1986, p.6). In hard-rock areas the information that groundwater organisations provide often is not useful for individual farmers to assess returns to their investment. Even before groundwater utilisation exceeds gross recharge or water available for use (or the potential), individuals may no longer find it profitable to invest in wells unless they can get information necessary to tap existing aquifers at reasonable costs. High probability of failure discourages farmers from investing in wells unless covered by insurance. In western Maharastra, for example, the probability of striking groundwater in random digging is estimated to be less than one-third (Dhawan 1986, p. 6).

In the two sample villages also, investors faced the risk of not striking water. A yield of about 3 m^3 per hour is required for a well to be considered successful and to make pump installation worthwhile. At such low discharges, one may need to invest in water conservation techniques such as drip irrigation to irrigate a reasonably large area. A total of 23 wells constructed by the sample households, who are currently using 72 wells, did not yield sufficient water. That is, for every 3 successful wells there was one failed well. The rate of failure was higher among tubewells. There were 7 failed open wells (three with bores in them) compared to 37 successful ones. On the other hand, 16 tubewells did not yield sufficient water compared to 35 successful tubewells. While the probability of not striking water was only about 0.15 in the case of open wells, it was nearly 0.31 in the case of tubewells.

WELL UTILISATION

With fairly low yields/discharges, the wells in this village were barely adequate to meet the irrigation needs of their owners. The average gross area irrigated per well was 2.73 hectares. But it differed among well types as yields did. DCBs, which had the lowest yield, irrigated only 1.46 hectares[5], OWs 2.67 hectares and TWs 3.39 hectares. As 72 wells in these two villages are owned by 55 households, there are several families which own more than one well. As one might expect, those with more than one well had larger holdings than others. The average landholding of households with one, two and three wells were 4.28, 5.1 and 11.0 hectares. The corresponding net areas irrigated per well by these households were 2.0, 2.01 and 3.2 hectares and the gross area irrigated were 2, 4.2, and 9.6 hectares. Those with larger holdings were able to irrigate more as they had more wells and also a larger proportion of their wells were TWs which irrigate more area per well (Table 3).

Table 3. Gross Irrigated Area Per Well and Cropping Intensity

	Average Landholding (ha)	Gross Irrigated Area (ha)	Irrigation Intensity (percent)	Adjusted Irrigation Intensity (percent)
Average for all wells		2.73		
Per well				
Open well	4.92	2.67	158.54	224.49
Dug-cum-bore well	4.30	1.46	136.19	205.56
Tubewell	5.19	3.39	157.98	242.20
per household with				
One well	4.20	2.80	155.76	219.29
Two wells	5.10	2.01	158.48	236.67
Three wells	11.00	3.20	145.45	275.76

The average gross area irrigated per well-owning household was 3.5 hectares. Gross areas irrigated by households with holdings of up to 2, 2 to 4 hectares, from 4 to 6 hectares, and above 6 hectares were 1.86, 2.0, 3.2 and 6.67 hectares. In all cases, the irrigation intensity, that is the gross irrigated area over net irrigated area, was nearly 150 percent. Gross irrigated area per well in 1974 in Doddaballapur taluka, Bangalore district and Karnataka state were 1.34, 1.32, and 1.53 hectares. Irrigation intensity is little more than 150 percent, as much of the irrigation takes place in kharif to augment rainfall (GOK 1975).

MARKET FOR IRRIGATION SERVICES

Although there was no well established market in terms of large number of exchanges and established terms of exchange, there were exchanges between well-owners and non-well-owners. Fourteen well-owners indicated that they had supplied water to other farmers in exchange for payment of some kind. All but one of these households provided irrigation services to only one other household. Four well-owning households which did not

[5] Dug-cum-bore wells yield less than open wells though they have bores in them as bores are drilled only in open wells which have poor yields.

provide services to others purchased services from well-owning households. Only two households without wells in our sample indicated that they had purchased irrigation services. It is possible that water sharing is more extensive than is suggested by our data, as water exchanges were often linked with those of other inputs and many did not see these as exchanges in irrigation services.

The most common method of paying for irrigation services is through a share of the crop. Fifteen of the farmers who either sold or purchased services indicated that the payment was a crop share. Four others paid a fixed fee per unit area irrigated. There was only one case in which the payments were on the basis of hours of supply. A third of the crop output was the most common charge for irrigation services. There was a case in which the charge was only one-fifth of the output and another in which the share was one-half. Ragi was the crop most frequently irrigated with purchased services (9 cases) and about 0.8 tons is a third of the average yield under irrigation. For other crops, the per hectare share received by the well-owners varied widely. It amounted to Rs. 1,250 for tomato, Rs. 1,000 to Rs. 1,500 for mulberry, and Rs. 2,500 to Rs. 6,000 for potato. In two cases involving fixed charges per acre, the charges were Rs. 5,000 per hectare for potato and Rs. 3,750 per hectare for brinjal. The charges were Rs. 10 per hour in the only case of hourly charges. This was from a diesel well located in the tank command. Farmers purchased water from this diesel well for irrigating paddy whenever the tank dried up.

The exchanges in the market for irrigation services were often interlinked with the exchanges of other inputs such as land, labour and credit. The buyers of irrigation services often leased in land from the sellers, worked for wages on their fields or had borrowed from the sellers. In a few cases, the sellers had leased out land with assured irrigation. They received one-half of the output for providing both land and water compared to the one-third they would generally receive for leasing out only land. Some of them who leased out land with assured irrigation felt that they were providing water free of cost. In twelve cases, the buyers either worked in sellers' fields for wages, were tenants or had borrowed from them. In four cases, the buyers were also the sellers' relatives. Many well-owners seem to have leased out small parcels to those who work for them and provided protective irrigation to ragi which is generally raised during kharif. Apart from irrigation of cash crops the charges for which were fairly high, exchanges took place in kharif only when water availability was higher than in other seasons.

There was not much uniformity in irrigation charges in the village for two reasons. Water exchange was linked with either land, credit or labour exchanges and often negotiated individually. These interlinked transactions appear to be highly personalised (Bardhan 1984, p.159). What is charged for water is often concealed by charges for other inputs. There seem to be some uniformity in charges for ragi during kharif. The second reason is that water exchanges have taken place here even before the opportunity for well-owners to use on their own fields is exhausted. The charge that a well-owner would like to levy would depend on incremental returns to irrigation on his own land. As there was considerable fallowing among those with larger holdings, it appears as though there may have been labour shortage in the village. One or two farmers suggested that sellers charge for irrigation based on crop irrigated and expected returns. In such an approach the seller may be taking into account differences in water requirements and also attempting to capture some of the surplus produced because of the monopoly power. In general water exchanges seem to be been driven by i) protection of crops on land leased out to those who work for wages, ii) higher returns from sale of services than irrigation on own fields, and probably iii) obligation to provide irrigation to neighbours and relatives during scarce periods. Prices seem to reflect negotiated positions. These interlinked transactions need not be inefficient as they ensure "double coincidence of wants" (Bardhan 1984, p.161)[6]. Interlocking also gives an opportunity for the seller to avoid sanctions against charging high prices for water (Bardhan 1984, p.165).

IRRIGATION COSTS

Well costs depended on the type of wells. The historical average costs of OWs, DCBs and TWs were Rs. 25,600, Rs. 36,875, and Rs. 47,353 (Table 4). The costs of different types of wells are not strictly comparable as OWs are older than TWs. The current costs of OWs are likely to be more than one-half of the TW cost as suggested by our data. The TWs cost more because of higher expenses on pumpsets, pump houses, pipes/distribution system and survey. The investment cost per household, as many households owned more than one well, was Rs. 46,953. The average cost of failed wells was about Rs. 10,000 per household (Table 5).

Table 4. Capital Costs of Wells at Historical Prices

Items	Type of Well					
	OW (23)[1]		DCB (14)		TW (35)	
	Rs.	No.[2]	Rs.	No.	Rs.	No.
Well	14841	22	19431	13	10567	7
Casing	0		1547	11	3980	6
Pumpset	4059	17	9543	7	16398	23
Electrical	2959	17	3286	7	4857	23
Pump house	2000	19	3808	13	5019	27
Pipe	1668	14	1886	7	9757	27
Pond	500	1	438	7	950	3
Survey	0		0		468	22
Total	25,608	20	36,875	13	47,353	30

[1] the numbers in parentheses are number of wells of the type in the sample
[2] the number of wells for which the costs of corresponding items are available

[6] Interlocking of transactions may enhance the bargaining power of one party in relation to another (Bardhan 1984, p.165). We discovered through informal queries among flower growers in some of the villages in Madurai district that those leasing out land along with irrigation facilities were in a stronger position as such lands were in demand among those wanted to lease in.

Table 5. Capital Costs of Wells Per Farm (Rupees)

Particulars	Mean	S.D.	No. of Observations
Well	21,067	14,408	31
Casing	2,921	2,202	14
Pump	13,153	9,612	39
Electric connection	4,744	3,225	39
Pump house	4,551	4,469	49
Distribution pipe	7,143	18,460	42
Pond	890	988	26
Survey	572	264	18
Total	46,953	30,377	55
Cost of failed well	10,364	15,891	

The annual operating expenses which include electricity charges, lubricant, and repairs were about Rs. 1,450 per well. They ranged from Rs. 1,276 for OWs to Rs. 1,615 for TWs. Higher operating expenses for tubewells was due to higher electricity charges as they were fitted with prime movers of higher horsepower compared to OWs and DCBs. The operating expenses per household, that is for an average of 1.3 wells, was Rs. 1,827 per annum (Table 6).

Table 6. Annual Operating Costs Per Well and Farm (Rupees)

Item	All Types	OWs	DCBs	TWs	Per Farm
	(72)	(23)	(14)	(35)	(55)
Number of cases	61	21	13	27	48
Electric charge	755.4	660.0	595.4	906.7	941.25
	52.0	51.7	42.6	(56.1)	(51.5)
Lubricant	27.0	78.6	0.0	0.0	34.38
	1.9	6.2	0.0	0.0	1.9
Repairs	670.5	538.1	803.8	709.3	852.08
	46.1	42.1	57.4	43.9	46.6
Total	1453.0	1276.7	1399.2	1615.9	1827.71
	100.0	100.0	100.0	100.0	100.0

Note: Figures in parenthesis indicate per cent of total.
Out of 72 only 61 wells were operating. Of the remaining, 10 were new and one diesel. The costs are averages for the operating wells whose numbers are given at the top of the columns.

The fixed costs, depreciation and interest on capital varied according to the type of well. Average fixed costs were Rs. 3,841 for OWs, Rs. 7,375 for DCBs and Rs. 9,887 for TWs directly in proportion to their costs. Per household fixed costs were higher as they owned more than one well and often a combination of different type of wells. The average cost per household was Rs. 8,971 and it ranged from Rs. 7,143 for households with one well to Rs. 14,385 for households with three wells (Annex: Table 4).

The annual total costs of irrigation, that is the sum of fixed and variable costs, were Rs. 5,118 for OWs, Rs. 8,774 for DCBs and Rs. 11,530 for TWs. But as gross area irrigated was the lowest for DCBs, their average costs per gross hectare was the highest among the three types of wells. Average costs per gross hectare irrigated were Rs. 5,500 for DCBs, Rs. 1,917 for OWs and Rs. 3,280 for TWs (Table 7).

But the average costs of irrigating a gross hectare varied among owners having different sised holdings. Those with larger holdings had more and superior wells; therefore, their costs were lower. Those with three wells, for example, had average costs of only Rs. 2,046 per gross hectare compared to Rs. 3,089 and Rs. 3,729 for households owning one and two wells. These differences meant that those with largest holdings had per hectare average irrigation costs which were one-half of the average costs of those with the smallest holdings: Rs. 2,252 per gross hectare for those with holdings larger than 6 hectares compared to Rs. 4,832 per gross hectares for those with holdings less than 2 hectares (Annex: Table 3). As a result, irrigation costs accounted for about one-half of the total production costs for small farmers.

Table 7. Irrigation Costs

Items	OWs	DCBs	TWs
Average holding (ha)	4.92	4.30	5.19
Annual fixed cost (Rs)	3,842	7,375	9,887
Variable cost (Rs)	1,276	1,399	1,643
Total cost (Rs)	5,118	8,774	11,530
Gross irrigated area (ha)	2.67	1.57	3.52
Cost per hectare (Rs)	1,917	5,580	3,280

RETURNS

The base income from farming for estimating incremental income from irrigation was estimated from data on 40 households which did not irrigate any crops. The average annual income from these farms was 2,214 per net hectare. Gross returns on these farms was Rs. 2,745 per net hectare. The average costs were around Rs. 500, three-fifths of which was accounted for by fertiliser costs.

The average net income from a hectare of irrigated land was Rs. 15,336. It ranged from Rs.10,185 per net hectare on farms with less than 2 hectares to Rs.17,862 on farms with greater than 6 hectares. With the average investment for all well-owning households being about Rs. 50,000, the Internal Rate of Return (IRR) on investment was nearly 57 percent (Table 8).

Table_8. Internal Rates of Return from Well Investments

ItemsAll	Wells	Wells Belonging to Households Owning Land in ha			
		Below 2.0	2.01-4.0	4.01-6.00	Above 6
Av. gross irrigated area	3.44	1.61	1.90	3.28	6.56
Av. net cropped area	2.18	1.01	1.10	2.03	4.36
Av. net income from crops	35,352.3	12,028.0	14,050.2	30,804.1	80646.45
Annual operating cost of pump	1,846.6	1,842.5	1,730.9	1,369.4	2702.73
Income net of irrigation costs	33,505.7	10,185.5	12,319.3	29,434.7	77,943.7
Av. net income/ ha of NCA	15,336.6	10,084.7	11,199.3	14,504.0	17,862.1
Per ha. income from dry crops	2,214.2	2,214.2	2,214.2	2,214.2	2,247.6
Net incremental income /ha.	13,122.4	7,870.5	8,985.1	12,289.8	15,614.5
Net incremental income per farm	28,668.4	7,949.2	9,883.7	24,941.2	68,136.0
Initial investment	50,257.8	39,251.3	42,500.0	49,735.8	66,827.3
Simple rate of return	57.04%	20.25%	23.26%	50.15%	101.96%
Internal rate of return	56.39%	15.43%	19.26%	49.23%	101.87%

Due to differences in per hectare returns among households with different sized holdings, the IRR varies a great deal. For households with less than 2 hectares whose investment was about Rs. 40,000, the net incremental returns per farm was about Rs. 8,000 and the IRR was about 15. The IRR was slightly higher for households with 2 to 4 hectares. In households with holdings larger than 4 hectares the IRR exceeded 50 percent. The net incremental income per farm for households with more than 6 hectares was nearly 70,000 and it gave them a return of nearly 100 percent with initial investment of about Rs. 67,000. The investment was paid back in a year in large farms with more than 6 hectares.

The IRR to investments in wells in Maharastra were estimated to be around 15 percent (Dhawan 1986, p.74). The IRRs in Maharastra depended on how perennial the wells were. They ranged from 8 percent for wells which could irrigate in one season to 25 percent for those which could irrigate during three seasons. In Bangalore district, wells used in only one season and two seasons make about 30 percent each of the total wells and the other 40 percent of the wells are used in three seasons (GOK 1975).

The return varied a great deal across farms of various size because of differences in well utilisation, irrigation costs and agricultural productivity. The returns also varied by the type of wells. The returns for DCBs was the lowest as they irrigated the least area per well. The returns to OWs were high as their costs were at historical prices and therefore low (Annex: Table 5). The returns are estimated assuming 10-year life for the assets. Under hard-rock conditions, even deep tubewells which have high initial yields may go dry after a few years. To the extent that we are overlooking these risks that investors face, we are overestimating the true expected returns from well investments.

ACCESS TO IRRIGATION AND PRODUCTIVITY DIFFERENCES

Farmers can increase income from land by adopting one or more of the following: i) increase the number of crops grown on a piece of land in a year (or increase cropping intensity), 2) cultivate crops which give higher income per unit of land (crops/varieties which give higher yields or fetch higher price per unit of output), and 3) increase yields by application of more/ better inputs. The extent to which these strategies are adopted by those irrigating is reflected by differences in cropping intensity, cropping pattern, input use, and yields between those with and without irrigation facilities.

Differences in access to irrigation which is of concern in the choice of institutions for groundwater development *are reflected by differences in cropping intensity*, *cropping* patterns and yields. The cropping intensity of households without wells was about 100 (Table 9). Those without wells irrigated some of their crops by purchasing irrigation services in addition to utilising tanks. Cropping intensity estimated by taking into consideration the duration of crops (referred to as adjusted cropping intensity in Table 9) for households without wells is about 110. In addition to irrigating some crops, some of them were raising eucalyptus without irrigation. The cropping intensity of households with wells was 137 percent. The difference was not large for reasons stated already; water availability was much less than required to irrigate all their land. But their adjusted cropping intensity was nearly 200. While well-owning households irrigated about 63 percent of the GCA, households without wells were able to irrigate only about 9 percent of the GCA. Much of this was paddy irrigated by the tanks in the villages and other crops irrigated by purchasing irrigation services (Annex: Table 6).

Table 9. Cropping Intensity

Household Category	Holding (ha)	Gross Cropped Area (ha)	Net Cropped Area (ha)	Cropping Intensity (percent)	Adjusted Intensity (percent)
All households	2.82	3.23	2.56	126.2	177.2
a) With well	4.71	5.82	4.36	133.6	197.3
b) Without well	1.24	1.08	1.07	101.1	109.4
a) Margina	10.51	0.55	0.55	100.0	100.0
b) Small	1.52	1.75	1.48	117.9	134.6
c) Medium	2.84	2.74	2.31	118.3	166.4
d) Large	6.23	7.57	5.69	133.0	197.5

These differences between well-owners and others in cropping intensity leads to a direct relationship between size of landholding and cropping intensity. Households with wells had average holding of 4.71 hectares compared to 1.24 hectares among non-well-owners. All marginal farmers and two-thirds of the small farmers did not own any well. Around 75 percent of the medium and most of the large farmers owned at least one well. Cropping intensity, therefore, was higher among households with larger holdings. Adjusted cropping intensity was 100 percent for marginal farmers, 135 percent for small farmers, 166 percent for medium farmers, and 198 percent for large farmers (Table 6).

The differences in access to irrigation also led to significant differences in cropping patterns and productivity. Households without wells planted food crops on nearly 83 percent of their cropped area while well-owning households planted cereals on only 43 percent of the cropped area (Table 10). Food crops comprised only paddy and ragi. Well-owning households cultivated commercial crops on 30 percent of the GCA compared to only 2.5 percent for other households. These commercial crops included crops whose produce are sold: vegetables, popcorn and maize, watermelon, etc. Vegetable cultivation was extensive. Fifty-five well-owning households grew around 36 different vegetables. The balance, that is about 14 percent and 24 percent of GCA of households without and with wells, was devoted to plantation crops. Nearly all of this was planted with eucalyptus by households without wells. Well-owning households planted eucalyptus, guava, mulberry, coconut and other fruit trees. The well-owners were able to switch their cropping pattern in favour of horticultural crops because of access to groundwater irrigation. The location of the village nearby a large city and fairly well established transport seem to have enabled them to commercialise their agriculture.

Table 10. Cropping Pattern

Crop Category	Percent of Gross Cropped Area Planted in Households		
	All	With Well	Without Well
Food	49.97	43.43	82.48
Commercial	24.82	29.35	2.34
Other annual	3.10	3.53	1.00
Plantation	22.10	23.70	14.19

Just as cropping intensity was related to holding size, cropping patterns also varied across holding categories. Nearly 96 percent of the GCA of marginal farmers was devoted to cultivation of cereals. Nearly all of it was ragi. Only some of those who had access to irrigation from the tank grew paddy on nearly 2 percent of GCA. Small farmers, on the other hand, grew cereals on 70 percent of the land, commercial crops on 20 percent of the land and plantation crops on the remaining 10 percent of GCA. Households in the largest holding category cultivated cereals on about 41 percent of GCA, commercial crops on about 32 percent and plantation crops on about 25 percent of GCA. It is interesting to note that only the middle and large holding households had planted eucalyptus (Annex: Table 7). Among well-owning households, however, there was not much differences between households of different holding sizes in commercialisation. Small farmers had the largest share of GCA (24 percent) planted with vegetables compared to about 15 percent for other categories. Large farmers similarly had devoted a greater share of their GCA to plantation crops (30 percent) compared to others (15 to 23 percent) (Annex: Table 8).

The third factor, in addition to higher cropping intensity and more profitable cropping patterns, which contributed to differences in value of production was yields. Yield comparisons can be made for only a few crops between the two categories of households as ragi and paddy are the only two crops they have in common. Rainfed ragi and tank-irrigated paddy yields were both higher for well-owning households compared to other households. Average yield of rainfed ragi for well-owning households was 1.37 tons per hectare compared to 0.87 for other households. Similarly, paddy yields of well-owning households were 4.62 tons per hectare compared to 2.5 tons for other households.

Higher levels of chemical fertiliser application by well-owning households may account for their higher yields. Well-owning households applied 91 kilos of nitrogen, phosphorous and potash (NPK) per hectare compared to 61 kilos by other households. Similarly, for tank-irrigated paddy well-owning households applied nearly 200 kilos of NPK (111 of N, 46 of P, and 42 of K) per hectare compared to 130 kilos per hectare by other households. The differences may have been largely due to higher risk-taking ability and access to credit of well-owning households.

As a result of differences in intensity, cropping patterns and yields, differences in net incomes between households with and without wells were large. Gross value of outputs produced by households with wells was Rs. 14,730 per hectare of NSA compared to Rs. 3,186 for households without wells. The differences were significant between households in different landholding categories also. Gross value of output per NSA ranged from nearly Rs. 2,000 on marginal holdings to about Rs. 15,000 on large holdings (Table 11). The difference in net values of output per NSA was smaller but still significant. It was three times larger for well-owning households (Rs. 6,621 compared to Rs. 2,265). Net output values ranged from Rs. 1,200 per net hectare on marginal holdings to Rs. 7,500 per net hectare on large holdings.

Table 11. Gross and Net Returns Per Hectare

Farm Category	Net Returns			Gross Returns		
	Per Cultivating Household	Per Hectare of G.C.A.	Per Hectare of N.S.A	Per Cultivating Household	Per Hectare of G.C.A.	Per Hectare of N.S.A
All households	14,414	4,457	5,625	30,982	9,58	112,091
a) With well	28,846	4,954	6,621	64,175	11,022	14,730
b) Without well	2,428	2,240	2,265	3,416	3,151	3,186
a) Marginal	691	1,256	1,256	1,067	1,938	1,938
b) Small	3,495	2,002	1,352	9,855	5,645	6,658
c) Medium	7,359	2,688	3,179	19,531	7,135	8,438
d) Large	42,773	5,650	7,512	87,606	11,571	15,385

ALLIED ACTIVITIES

Access to irrigation also seem to have facilitated undertaking of ancillary activities such as silkworm rearing and dairying. Both of these activities require inputs: mulberry for silkworm rearing and green fodder for dairying whose cultivation requires irrigation. However, it is also true that access to agricultural land is not required for silk worm rearing or dairying if these inputs can be purchased. In addition to the inputs which are grown, silkworm rearing and dairying require skilled/knowledgeable labour and capital investment.

Among the 16 households which were engaged in silkworm rearing, 12 were well-owning households. The other four households purchased mulberry leaves from well-owning households. The scale of operation of well-owning households was larger. They raised more number of crops in a year (4.1 compared to 2.5) and their average crop size was also higher (194 to 82 hundred eggs). Though households without wells obtained higher yields per 100 eggs (30 kgs compared to 22 kgs) and prices, their net income per family was less than one-half of those of well-owning households (Rs. 2,855 compared to Rs. 7,955) because of differences in the scale of operation.

In dairying there was greater uniformity between the two groups. Out of 67 households engaged in dairying 48 owned wells and the remaining 19 did not. Well-owning households maintained an average of 3 cows compared to 1.3 in the households without wells. Daily milk production and number of milking days in a year were both higher for well-owning households because of their larger herd size and possibly greater availability of green fodder. Households with no access to irrigation did not grow green fodder; they fed the cattle with various grasses and weeds which grow on the bunds and grased their cattle in open fields. Net income over maintenance expenditure among well-owning households was Rs. 4,722 per year compared to Rs. 3,649 per year among other households.

WELL-OWNERSHIP AND INCOME DIFFERENCES

The average landholding of the well-owning households was nearly 4 times that of the other households. Also those with larger holdings invested in more wells. The average landholdings of those with one, two, and three wells were 4.0, 5.1, and 11.0 hectares. Nearly a third of the well-owning households also had at least one member of the households working on off-farm jobs. They were better educated. Their average income from non-farm jobs at Rs. 13,237 per year was more than twice that of the other households. Non-farm incomes came from farm work wages, salaries, rent of bullocks or tractors, sale of birds and animals and other small businesses (Annex: Table 9).

Table 12. Household Incomes

Household Category	Income Source				Total
	Agri Crops	Silkworm Rearing	Dairy	Non-farm Income	
All	14,414	6,680	4,418	9,613	35,126
a) With well	28,846	7,956	4,722	13,237	54,761
b) Without well	2,249	2,855	3,650	5,852	14,606
a) Marginal	692	3,643	4,603	5,617	14,555
b) Small	3,496	7,091	3,646	13,086	27,319
c) Medium	7,360	3,037	4,678	9,241	24,316
d) Large	42,774	10,768	4,528	17,523	75,593

The total annual income of well-owning households was nearly Rs. 55,000 compared to Rs. 15,000 for households without wells (Table 12). This includes income from crop cultivation, silkworm rearing, dairying and non-farm income. While well-owning households earned nearly one-half of their income from crop cultivation, those without wells received only 15 percent of their income from cropping. Nearly 40 percent (Rs. 5,800) of the income of the households without wells came from non-farm activities. The income of households with marginal holdings was the same as that of households without wells. But there was a large difference in total income between households with large holdings and the other two medium categories. Large holdings had income of nearly Rs. 75,000 compared to about Rs. 25,000 for small and medium holdings. Much of this was because of very high crop incomes in large holdings.

SUMMARY AND POLICY IMPLICATIONS

In regions with hard-rock aquifers, inadequate rainfall, no surface irrigation and commercialisation of agriculture spurned by access to markets particularly for vegetables and fruits, considerable pressure is put on groundwater for irrigation. Groundwater use in excess of annual replenishment or mining of groundwater leads to lowering of groundwater table requiring larger investments for water extraction and changes in technology of water extraction. OWs have to be replaced by deeper TWs and submersible pumps become necessary. A shift also takes place in the energy source used; electricity is required for pumping water from deep tubewells. Though farmers may incur lower extraction costs by shifting from diesel to electric pumps because of the current low and flat charges for electricity, they become vulnerable to erratic power supply. There may be a loss of water control or the ability to irrigate crops as and when they desired.

As the data from the two villages in Karnataka shows, declining water tables combined with increasing probability of not striking water leads to increase in capital and consequently average extraction costs. Old OWs have been abandoned and only deep TWs are now used for water extraction. The average cost of a TW in this location now is about Rs. 50,000 compared to about Rs. 12,000 in a water-abundant region such as east Uttar Pradesh (Kolavalli, Naik and Kalro 1993). The estimated cost per successful TW in the region as a whole works out to about Rs. 62,500 assuming that costs of failed wells are about 50 percent of successful wells. Requirement of such large funds preclude small and marginal farmers from well-ownership because of difficulties in gaining access to credit. On average, every third tubewell fails to yield adequate water. The chances of well failure also discourages smaller farmers, as any failure will have catastrophic effect on them unless they are covered by insurance.

Markets for irrigation services provide an opportunity for households without wells to purchase irrigation services from well-owners. But the number of transactions in irrigation services are likely to be minimal in regions with water scarcity for reasons related to both supply and demand for irrigation services. As the "surplus" or the capacity of wells to irrigate in excess of the needs of the well-owner is likely to be much smaller, supply of services is likely to be constrained. The owners would be willing to sell irrigation services only if the returns exceed returns to irrigation on their fields. A fairly high willingness to pay for irrigation services is required for an exchange to take place. Many water transactions are also likely to be tied up with exchange of other inputs such as labour, land and credit. Another factor which may lead to fewer exchanges is the transaction costs involved in developing and enforcing contracts given uncertain well yields and power supply. The reason for lack of water transaction need not be inhibitions and taboos as stated by Shah (1991, p. 338) but large gaps between well-owner's opportunity costs and WTP of buyers and large transaction costs under scarcity conditions.

Differential access to groundwater irrigation leads to significant differences in income between household with and without wells and households with landholdings of different sizes. Net value of production was significantly higher on larger holdings. Households with larger holdings which had better access to irrigation had nearly 50 percent of their gross cropped area under commercial and plantation crops. They obtained higher yields as they irrigated more area and the quality of their irrigation also tended to be better because they owned superior sources such as TWs.

High incremental returns to irrigation and higher returns on larger holdings compared to smaller holdings are due to the nature of commercialisation in the two villages. Irrigation is associated with production of commercial crops, mostly perishables sold in the nearby metropolitan area. There is considerable price risk associated with fruits and vegetables. Our

Table 13. Effect of Failure Rate on Regional and Individual Returns

Probability of Failure	Incremental Returns Per Net Sown Hectare[1]	IRR for the Villages[2].	Expected Net Present Value	IRR for a Successful Well
0.31	14,500	0.46	44294	0.57
0.31	11,200	0.35	25796	0.44
0.31	10,000	0.31	19069	0.39
0.31	8,000	0.24	7858	0.30
0.31	6,000	0.16	-3353	0.21

[1] IRR is estimated assuming irrigation of 2 hectares.
[2] Capital costs include the cost of failed wells.

High returns on larger farms continue to increase disparity from unequal access to groundwater as they provide larger farmers with incentives to invest in groundwater even if the probability of not striking water is positive. As the probability of not striking water increases the returns to investments for the region as a whole decrease as the capital costs per successful unit increase. The probability of failure for tubewells in the two villages studied was 0.31. The effect of failure rate on IRRs assuming various levels of incremental returns per hectare are given in Table 13. When the incremental return is as high as Rs. 14,500 per hectare the IRR for the region is about 10 percent less than it is for a successful well.

An individual farmer makes investment based on the expected returns. A farmer in the two villages is faced with 0.31 chance of not striking water and therefore incurring a loss of nearly Rs 25,000 and 0.69 chance of receiving some incremental returns over the life of the well. The expected returns from investments for the individual given 0.31 chance of a well failing are given in column 4 of Table 10. The expected value from investment becomes negative only when incremental return is as low as Rs. 6,000 per hectare. As seen in the last section, the incremental returns on large holdings were higher than Rs. 11,200 per hectare. For large holdings expected returns would become negative only at higher probabilities of failure (even more than one in two). Therefore, as long as the returns are attractive, as they are in these two villages, the larger farmers will continue to find it attractive to invest in wells. This is assuming that loss will not have catastrophic effect on the livelihood of the investors[7]. If one has borrowed funds which need to be paid back with no production base, probability of failures may deter investments. The poor may shy away from investment under these conditions unless they are insured against losses[8]. The larger farmers are also better able to invest in water

[7] The investments in the two villages were financed by personal savings, borrowed funds from commercial and development banks, and land development banks. Only one household reported borrowing from a moneylender. Thirty-three of the fifty-five households had borrowed funds. Borrowed funds accounted for about 50 percent of the investment.

[8] There are several programmes under which farmers can choose to pay considerably high drilling charges if wells are successful and not pay anything if the well is dry.

conservation mechanisms such as sprinklers, drip irrigation particularly for plantation crops, and underground pipes to distribute water. Those who have access to resources will continue to invest in better technology to exploit available water which makes water increasingly less accessible to those who cannot invest or have access to only poor technologies.

The mechanisms to achieve broad objectives of groundwater development, viz. efficiency, equity and sustainability, should be location specific because the conditions under which groundwater is available (and consequently how it can be extracted) and the benefits from using groundwater vary considerably from one region to another. The external benefits and costs from groundwater use also differ from one region to another. While groundwater use can yield drainage benefits in regions with high water table, they impose external costs in scarce areas by running shallow wells dry and increasing future extraction costs.

While private exploitation of groundwater can be efficient in hard-rock conditions, it may not lead to equitable or sustainable practices. As suggested above, high investment costs deter small and marginal holders. Limited availability of water also results in a thin market for irrigation services which in water abundant regions provide wide access to households without wells. Hard-rock conditions also offer few other options to increase access as deep tubewells to be managed publicly are not feasible even assuming that they can be managed properly. Joint ownership is also not attractive to investors because of the uncertainties involved. The potential for conflicts is quite high given the chances of failure and sharing of limited water. Many farmers would therefore shy away from joint ventures.

Sustainable groundwater use is considered to be one in which annual use is less than what is annually replenished (O'Mara 1988). But if water is to be an exhaustible resource or if groundwater is a stock which is not replenished, the optimal level of exploitation is not zero. Just as with petroleum, groundwater should be extracted keeping in view the opportunity cost of extracted water not being available for future use. A private developer would keep this opportunity cost in view if he had rights to water. On the whole, unfettered private exploitation may not lead to sustainable groundwater use.

Markets for irrigation services and public tubewells are two mechanisms through which access to groundwater can be extended. Though a greater share of the rent is extracted by the water supplier in the case of markets compared to public tubewells, the buyers become considerably better off compared to a situation without access to groundwater. But when well yields or surpluses are low, a condition under which market exchanges are sparse, public tubewells are also infeasible. The only hope for those without access is improvement in water harvesting and dry farming techniques themselves.

Rainfall harvesting techniques if implemented have considerable potential to benefit the whole community. But practices which involve low technology and community effort are disregarded in favour of high technology measures which involve individual efforts only. There is evidence from the study that traditional means of irrigation such as tanks have been neglected. The tank at Thimmasandra is heavily silted and the area which can be irrigated has been considerably reduced. Desilting will increase water available for irrigation and also replenish wells downstream. Though this may disproportionately benefit larger farmers who are well-owners, it has spillover benefits to the overall economy through increase in demand for labour. Water harvesting will also revive wells which are being discarded as a result of lowering of groundwater table by withdrawals from tubewells.

Because of association between new agricultural technology and irrigation on the one hand and irrigation and land ownership on the other, land becomes the major determinant of access to new technology in water scarce areas. Households with small holdings, though legally entitled to institutional funds for irrigation investments, hardly benefit from such projects because of their own reluctance arising out of the associated risks or because of the bureaucratic hurdles placed between them and such programmes.

The breakdown of household income on the basis of source suggests that agriculture is the main source of income for only those households with access to irrigation. For example, marginal farmers who do not own wells earn only about Rs. 700 from crop husbandry out of their total annual income of about Rs. 14,500. Their other sources of income are non-farm jobs, dairying and silkworm rearing. The implication is that agriculture without irrigation simply cannot sustain even landholders. Adequate irrigation cannot be provided to everyone in a water scarce area. Alternative job opportunities have to be thought about.

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ANNEX

Table 1. Landholding in the Sample Villages

Category	Timmasandra				Rajghatta				Total			
	Population		Sample		Population		Sample		Population		Sample	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Less than 1 ha	78	49	8	15	154	61	21	37	232	56	29	26
1.01 to 2.0 ha	29	18	13	25	41	16	14	25	70	17	27	25
2.01 to 4.0 ha	26	16	13	25	44	17	9	16	70	17	22	20
Above 4.01 ha	26	16	18	34	13	5	12	21	39	9	30	27
Total	159	100	52	100	252	100	56	100	411	100	108	100

Table 2. General Information on Wells

Item	Type of Well			
	OW	DCB	TW	All
Total number of wells	23	14	35	72
Number of pumpsets[1]	21	13	30	64
Number of pump houses	21	13	30	64
No. of pucca pump houses	20	13	28	61
Pump houses guarded at night	18	12	28	58
Pump houses used for storage	18	12	28	58
Wells fitted with distribution system	16	7	28	51
Wells with storage pond	1	4	23	28

[1] All but one were electric.

Table 3. Cost of Irrigation of Well-Owning Households by Landholding

	Households	Below 2 ha	2.01 - 4.00 ha	4.01 -6.00 ha	Above 6.01 ha
1. Wells per household	1.31	1.11	1.18	1.33	1.64
2. Operating wells per household	1.24	1.13	1.17	1.17	1.55
3. Annual fixed cost	9033.6	7146.5	7613.6	8733.7	12316.6
4. Annual variable cost	1827.7	1842.5	1730.9	1345.6	2702.7
5. Annual total cost	10861.3	8989.0	9344.5	10079.3	15019.3
6. Av. gross irrigated area	3.50	1.86	2.00	3.20	6.67
7. Cost per hectare	3105.3	4832.8	4661.7	3149.8	2252.1

Table 4. Cost of Irrigation by Number of Wells Owned Per Household

	All	Households Owning ...... Wells		
		One	Two	Three
1. Average number of wells	1.31	1	2	3
2. Av. ownership holding	1.24	3.93	5.07	11.00
2. Annual fixed cost	8971.7	7,143.3	12,920.7	14,385.0
3. Annual variable cost	1808.8	1,501.5	2,081.5	5,260.0
4. Annual total cost	10780.4	8,644.8	15,002.2	19,645.0
5. Av. gross irrigated area	3.40	2.80	4.02	9.60
6. Cost per hectare	3170.0	3,089.4	3,729.0	2,046.4

Table 5. Incremental Income by Type of Well

	Open	Dug-cum-bore	Tube
Av.GCA (ha)	3.2	1.32	3.21
Av.NCA (ha)	1.97	0.94	2.09
Av. net income	33,594.61	10,289.75	35,441.59
Av. annual operating	1,477.50	1,684.29	1,473.57
Av. net income	32,117.11	8,605.47	33,968.02
Net income/ha of NCA	16,330.73	9,171.01	16,286.04
Av. annual income/ha	2,247.60	2,247.60	2,247.60
Net incremental	14,083.13	6,923.41	14,038.44
Net incremental	27,696.83	6,496.47	29,280.17
Total capital	25,795.83	37,315.00	49,350.71
Simple rate of return	107.37	17.41	59.33
I. R. R.	107.30	11.60	58.75

Table 6. Cropped and Irrigated Area

Season/Cropped and Irrigated Area	All Households		With Well		Without	
	Area	% to Gross	Area	% to Gross	Area	Well % to Gross
1. Kharif						
Total cropped area	202.97	56.74	152.15	51.09	50.82	84.81
Total irrigated area	77.564	39.95	73.064	38.77	4.5	78.95
% area irrigated	38.21		48.02		8.85	
2. Summer						
Total cropped area	45.2	12.63	44.6	14.98	0.6	1.00
Total irrigated area	45.2	23.28	44.6	23.66	0.6	10.53
% area irrigated	100		100		100	
3. Rabi						
GCA	30.5	8.53	30.5	10.24	0	0.00
GIA	28.6	14.73	28.6	15.18	0	0.00
% area irrigated	93.77		93.77		0	
4. Plantation crops						
GCA	79.07	22.10	70.57	23.70	8.5	14.19
GIA	42.8	22.04	42.2	22.39	0.6	10.53
% irrigated	54.13		59.80		7.06	
5. Total						
GCA	357.74	100.00	297.82	100.00	59.92	100.00
GIA	194.16	100.00	188.46	100.00	5.7	100.00
% area irrigated	54.28		63.28		9.51.	

Table 7. Cropping Pattern by Landholding

	Marginal	Small	Medium	Large
1. Food crops				
Ragi	94.62	62.9	41.66	31.72
Paddy	1.79	6.33	8.18	9.30
Total	96.41	69.31	49.84	41.02
2. Commercial crops				
Vegetables	0.00	12.66	10.50	18.06
Popcorn & maize	0.00	4.29	7.00	9.62
Water melon	0.00	1.29	0.91	3.89
Total	0.00	18.25	18.41	31.57
3. Other annual crops	2.39	3.01	4.72	2.62
4. Plantation crops				
Eucalyptus	0.00	0.00	18.44	8.79
Guava	0.00	1.29	3.65	6.47
Mulberry	1.20	2.58	3.80	1.88
Coconut	0.00	1.72	0.00	2.62
Others	0.00	3.86	1.14	5.03
Total	1.20	9.44	27.04	24.79
TOTAL	100.00	100.00	100.00	100.00

Table 8. Cropping Pattern of Well-Owning Households by Landholding

Crops	Small	Semi-medium	Medium	Large
1. Food crops				
Ragi	40.6	42.1	35.9	29.0
Paddy	5.3	9.1	8.4	9.5
Total	45.9	51.3	44.3	38.4
2. Commercial crops				
Vegetables	23.6	13.6	19.4	17.5
Popcorn & maize	7.4	8.8	12.5	7.1
Watermelon	2.8	0.8	1.8	5.3
Total	33.8	23.1	33.8	30.0
3. Other annual crops	5.5	2.1	2.1	
4. Plantation crops				
Total	14.8	23.5	19.8	29.4
TOTAL	100	100	100	100

Table 9. Non-farm Income of Households by Well Ownership and Landholding

Table 5.6 : Total Annual Non-farm Income of Households According to Well Ownership Status and Farm Size of the Households

Farm Category	Wages from Farm Work	Salaries from Off-farm Jobs	Rent (Bullock and Tractor)	Other Business	Sale of Birds and Animals	Total
All households	1,587	4,667	306	2,733	320	9,613
	17	49	3	28	3	100
a) With well	205	8,138	436	3,829	629	13,237
	2	61	3	29	5	100
b) Without well	3,021	1,064	171	1,596	0	5,852
	52	18	3	27	0	100
a) Marginal	4,172	248	266	931	0	5,617
	74	4	5	17	0	100
b) Small	1,102	8,689	50	3,244	0	13,086
	8	66	0	25	0	100
c) Medium	937	4,255	0	3,000	1,050	9,241
	10	46	0	32	11	100
d) Large	0	12,520	800	3,820	383	17,523
	0	71	5	22	2	100

WHEN GOOD WATER BECOMES SCARCE: OBJECTIVES AND CRITERIA FOR ASSESSING OVERDEVELOPMENT IN GROUNDWATER RESOURCES

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Abstract

Over the past four decades groundwater development in India has grown exponentially. As a result, problems such as long-term declines in water levels, high well failure rates, saline intrusion and other water quality concerns are emerging in numerous areas. Emerging problems have led to a broad, but relatively unstructured, debate concerning groundwater development levels and directions. Defining appropriate levels of groundwater development is a subjective process highly dependent on the implicit social objectives for which the resource is being exploited. Numerous objectives including sustained yield maximisation, equity in access, economic efficiency, drought buffer provision, and environmental maintenance regularly emerge, however, in the groundwater development debate. As groundwater overdevelopment occurs, scarcity brings goals into conflict. As a result, social debates over groundwater management are gaining in intensity. Data, information on groundwater conditions and associated social factors, are the currency of this debate. In this context, the criteria by which groundwater development and its impacts should be evaluated along with formal statements of management goals assume critical importance.

Formal statements of goals -- be they in policy documents or the legal framework defining rights to groundwater use -- define the standing of different uses and users relative to each other. They often influence who is allowed to participate in water policy and allocation debates. The criteria through which development patterns are monitored determine societies' ability to measure how closely field realities match goal statements. They also influence the ability of different actors to protect the rights they are allocated through policy and legal documents.

This paper outlines and discusses: 1) the goals that emerge regularly in the groundwater development debate; 2) some of the criteria by which development levels can be evaluated relative to different social goals; 3) the social implications of different goals and criteria; and 4) the implications of different goal and criteria choices for groundwater organisation design and activities.

I INTRODUCTION

Over the past four decades groundwater development in India has grown exponentially. Diesel and electric pumpsets numbered over 12.5 million in 1990 and have increased at a continuous growth rate of over 12% since 1950 (Dadlani 1990). It is estimated that thirty-five million hectares, roughly 42% of India's irrigation potential, can be served by groundwater (Saksena 1989, Dhawan 1990). Although official estimates of groundwater availability for future uses remain optimistic, problems such as long-term declines in water levels, high well failure rates, saline intrusion and other water quality concerns are already emerging in numerous areas (Moench 1991 & 1992, Bandyopadhyay 1989, Ghosh & Phadatare 1990a, GOG 1992, Goldman 1989, Reddy 1989).

Emerging problems have led to a broad, but relatively unstructured, debate concerning groundwater development levels and directions. Defining appropriate levels of groundwater development is a subjective process highly dependent on the implicit social objectives for which the resource is being exploited. Resource evaluation procedures adopted by Central and State governments (GOI 1984) are based around the concept of sustained yield. They seek to maximise the amount of irrigation development possible after reserving a portion of the groundwater resource to meet drinking and domestic uses. Full development is defined as the point where extraction equals recharge. Numerous objectives other than maximising the irrigated area regularly emerge, however, in the groundwater development debate. Equity in access to groundwater resources and how to achieve it is a hotly debated topic.[9] Economic efficiency is another goal -- particularly since over 20% of India's electricity production (and in some states much more) goes to pumping groundwater (Dadlani 1990). Wider social goals such as the provision of a buffer against drought and environmental maintenance also regularly emerge. Finally, there is the question of goals where groundwater cannot be treated as a renewable resource -- a situation which is probably much more common in arid sections of India than is generally recognised.

Closely linked with development goals lie questions over the criteria by which groundwater development and its impacts should be evaluated. Under the sustained yield approach followed in India, overdevelopment is typically recognised when long-term water table declines or water balance estimates suggest that extraction is greater than recharge. Other criteria, such as changes in water quality, seasonal fluctuations in availability, access equity, and the economic rationality or financial viability of further development, are rarely integrated in analyses of development levels.

Goals and the criteria against which the social desirability of existing development patterns can be measured are important. Formal statements of goals -- be they in policy documents or the legal framework defining rights to groundwater use -- define the standing of different uses and users relative to each other. They often influence who is allowed to participate in water policy and allocation debates. The criteria through which development patterns are monitored determine societies' ability to measure how closely field realities match goal statements. They also influence the ability of different actors to protect the rights they are allocated through policy and legal documents. Criteria which require technical sophistication to generate or evaluate are often poorly understood and impossible to challenge

[9] See many of the papers presented at the Workshop on Efficiency and Equity in Groundwater Use and Management, Institute of Rural Management, Anand, Gujarat (1989).

by less educated sections of society. Their use effectively allocates power to sections of society with access to appropriate technicians. Criteria which are less technically sophisticated give larger sections of society access to water management debates. Finally, on an administrative level, goals and criteria have a major impact on the appropriate structure and activities of groundwater organisations. Goal statements have implications for the relative balance of technical and service functions within state groundwater departments. Criteria strongly influence the types of data groundwater organisations need to collect and the ways in which those data should be analysed.

The purpose of this paper is: 1) to outline and discuss the goals that emerge regularly in the groundwater development debate; 2) to identify some of the criteria by which development levels can be evaluated relative to different social goals; 3) to discuss the social implications of different goals and criteria; and 4) to identify the implications of different goal and criteria choices for groundwater organisation design and activities. The often conflicting objectives implicit in debates over groundwater development are discussed first. This is followed by a section on the possible criteria for evaluating groundwater development relative to these objectives. Implications for groundwater organisations are drawn in the final section.

II OBJECTIVES

The statement that "groundwater resources are showing signs of overdevelopment" generally depends on a set of value judgements by its author regarding the objectives and extent of development appropriate. These value judgements are rarely explicitly identified. They are important, however, because they define what is meant by "overdevelopment." The variety of objectives identified in the introduction -- sustainable increases in food production, equity in access, environmental maintenance, economic viability, etc.. -- have led to an underlying confusion in debates over the extent of development desirable. Areas may be underdeveloped from a sustainable extraction point of view but overdeveloped from equity, economic, or environmental maintenance perspectives. The reverse can also be true. The following discussion provides a preliminary outline of some of the objectives implicitly underlying the current debate over groundwater development.

A) Maximum Sustained Yield

Two themes underlie India's official approach to groundwater development. These are: 1) the natural rights of the population to basic resources (such as drinking water) that are necessary for survival and; 2) maximising irrigation development in order to achieve food security. The National Water Policy gives first priority in water allocation to "fundamental rights" for drinking and domestic use. Agriculture has second priority followed by industry (Ghosh & Phadtare 1990b, p.434).

On a practical level, the relatively small magnitude of drinking and domestic needs relative to water requirements for agriculture coupled with India's long-term emphasis on food security has led to an emphasis on groundwater development for irrigation. Food security has been a particularly important goal in the post-Independence years. As the Report of the Irrigation Commission stated in 1972:

> "With the partition of India, the irrigation works were divided between the two successor States, but the distribution of the irrigated area was far from even. India got more than its share of population but less than its due share of land resources. It was deprived of the surplus grain-producing areas and most of the Indus irrigation system. As a result it became an importer of food grains. It was obvious that little could be done to increase production unless steps were taken to reduce the country's dependence on the monsoon. Hence, in the development plans which Independent India formulated, irrigation received high priority" (GOI 1972, p 73).

Drinking water and irrigation goals have not been seen as conflicting due both to the relatively small magnitude of drinking needs and to the view, widely held at least until recently, of groundwater as an unlimited resource. The ultimate sustainable groundwater irrigation potential was recently estimated at 80 m.ha. by the Central Groundwater Board (Dhawan 1990a). Of this 33.75 m.ha. are possible to irrigate from existing wells (Kempaiah 1990, p.8; Saksena & Mishra 1990, p.4). With less than 40% of the theoretically sustainable irrigation potential developed, the protection of high priority but low volume uses, such as drinking, has not been seen as necessitating legislative or other management actions. The primary de facto national objective in groundwater development has, therefore, been maximising extraction within sustainable limits to support irrigation.

In practice the above objective has led to an implicit goal of increasing groundwater extraction to the point where it equals recharge. In allocating governmental assistance for well construction and pump installation, the level of groundwater development is defined by the estimated ratio of extraction to recharge (GOI 1984). As extraction approaches recharge, governmental support for further development is progressively limited and then stopped. Overdevelopment is defined as the point where extraction exceeds recharge.

Current debates often hinge on how to manage groundwater extraction so that it remains lower than the estimated recharge. Most groundwater development has been done in the private sector, often without government assistance. As a result, limits on development assistance have little effect on the sustainability of emerging utilisation patterns. Alternative proposals -- ranging from direct regulation of extraction to indirect economic or user group management -- are widely discussed as ways to meet sustained yield objectives.

The ability of any approach under discussion to meet sustained yield goals is open to question. The logic of the sustained yield approach is also debatable. Recharge rates are very low in many arid areas. If significant groundwater use is to occur, mining may be inevitable. In addition, full development as defined by the maximum sustained yield may conflict with other, equally valid, social objectives.

B) Economic Efficiency

The economic efficiency of investments in groundwater extraction is an important social objective. Resources allocated to groundwater development, be they direct financial investments or indirect subsidies, are drawn out of other potentially productive portions of the economy. In many cases, approaches taken to achieving the maximum sustained yield conflict directly with efficiency goals.

The provision of highly subsidised and, in some cases, free electricity supplies to encourage irrigation pumping is a particularly strong case in point. Over 30% of electricity production in Gujarat goes to pumping. Farmers pay a flat annual electricity tariff based on pump horsepower which works out to an average payment of Rs. 0.15/kwh while the cost of generation in Gujarat is roughly 1.18 Rs/kwh.[10] The difference has resulted in a loss of roughly 806 crore to the State Electricity Board.[11] Brownouts and power shedding are common and affect industrial and other users throughout the state. Similar situations are common in most Indian states.

While tensions between economic efficiency and maximising sustained yield in the electricity case are clear, more fundamental conflicts are, perhaps, more important. Sustained yield is a static concept. Economic efficiency pre-supposes dynamic adjustments in resource use patterns in response to shifting economic and resource availability conditions. In purely economic terms, development may become inefficient long before the maximum sustainable yield is reached. In many hard-rock areas, for example, transmissivity and yield are low. Capturing the full amount of recharge could require a highly dense network of deep wells each of which might only produce a minor amount each year. Alternatively, there may be sound economic reasons for mining groundwater (e.g. extracting more than the available recharge) particularly in areas where recharge rates are low and little use could occur within sustainable limits.

Under the economic efficiency objective, overdevelopment would occur when the social costs of development exceed the social benefits. The value of groundwater irrigation is certainly high. According to Daines & Pawar: "Statistics at the national level suggest that groundwater irrigation already accounts for 75-80% of the value of irrigated production in India..." (Daines & Pawar 1987, p.5). Most recent evaluations indicate that the economic rates of return are: 1) high (30-200%) for private investment in private tubewells; 2) lower (18-50%) but acceptable for private dugwells in hardrock areas; and 3) low (7-25%) for public wells of any kind (Daines & Pawar 1987).

Although published economic rates of return to private groundwater investment appear high, evaluating the true social cost-benefit ratio is complicated. As Daines & Pawar

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[10] A.H. Dhebar, GSEB Official, GSEB office, Sabrimati on 12/31/91.

[11] Times of India, June 4, 1992, Ahmedabad Edition, "Metering of farmers' power use favoured", front page.

note: "most of the available ex-post studies lack clear explanations or differentiated data which would allow for an unambiguous determination of `economic' measures" (Daines & Pawar 1987, p.5). Few estimates that I have seen for the economic returns to groundwater irrigation take the true (unsubsidised) costs of power, fertiliser, credit and other inputs into account when calculating returns. None of them estimate the opportunity cost -- for example of drought buffer protection -- from leaving the groundwater in place.

C) Equity

The goal of increasing equity in access to resources (jobs, health, credit, water, etc.) for all sections of society is a major theme in policy debates throughout India. As a result, increasing, or at least not decreasing, equity is taken as an assumed social goal when different groundwater development issues are debated. Groundwater development levels have distinct equity implications. Extraction technology is "lumpy". Falling water tables progressively limit the effectiveness of different extraction technologies. Those who can afford to regularly deepen wells and shift technologies (Persian wheel, to centrifugal pump, to submersible pump...) are able to maintain direct access to groundwater resources, others can't. Both water quality and availability problems tend to disproportionately affect the poor.

Equity goals are one justification used for the provision of highly subsidised electricity for irrigation pumping. They are also a source of contention when different management approaches to control overdevelopment, such as regulating well spacing, are debated. Given the small and often highly fragmented nature of landholdings in India, spacing regulations tend to work against smaller farmers. Other regulatory approaches have similar equity implications.

Equity goals are often in direct conflict with those of efficiency and maximising sustainable yield. The case of electricity subsidies is, once again, a particularly strong example. The provision of electricity at flat annual rates based on pump horsepower may help sections of the poor obtain access to groundwater directly or via the development of relatively equitable water markets (Shah & Raju 1989, Ballabh & Shah 1989). Flat charges, however, provide no economic incentive for efficient water or electricity use. They may also increase extraction rates -- a factor which conflicts with sustainability goals in overdeveloped areas (Shah & Raju 1989). Pump electrical efficiencies are, for example, often in the range of 13-27% -- well below the >50% that is easily achievable under field conditions (Patel 1991). Similarly, pump-owners in Mehsana District, an area of rapidly dropping water tables, often sell water at half dry season rates during the monsoon in order to maximise profits over the fixed electricity charges.[12] Since the costs farmers face do not vary depending on how much water or energy they use, there is no incentive for them to invest time, effort, or capital to improve use efficiency.

[12] Field visits in 1991-92.

The primary point here is that the pursuit of equity goals has been at the cost of efficient use and, potentially, sustainability goals. It is not even clear how well equity goals have been served. Some argue that flat annual charges and the presence of water markets enable those who lack the resources to dig their own wells to purchase water -- thus increasing access equity (Shah & Raju 1989, Shah 1989a,b). Others argue that water markets can be highly inequitable (Goldman 1989, Bhatia 1992). Furthermore, given the pervasive electricity shortages in India, inefficient use reduces overall availability of energy for pumping. It is not clear if the poor are better served by more equitable access to a pie whose size has been reduced by inefficiency or if they would be better served simply by efficient use patterns that effectively double the size of the pie.

An adequate summary of the water pricing and water market literature is beyond the scope of this paper. The debate over markets is, however, a key point where tensions between the goals become evident.

D) Drought Buffer

In many parts of India, groundwater resources are the only reliable source of agricultural, industrial, and drinking water supply in drought periods. During these periods groundwater has a much higher value than in normal rainfall years. From the drought buffer perspective, overdevelopment is occurring when sufficient stocks are not being maintained to meet requirements during droughts of predictable severity and length. Overdevelopment may also be occurring when recharge rates in excess of normal extraction do not permit resource recovery in the interval between droughts.

Drought buffer maintenance objectives can come in conflict with those for equity and efficiency in resource use. In many situations maintenance of a buffer against drought requires restrictions on use. As previously noted, restrictions tend to have negative equity consequences. Buffer maintenance may also require using less than the maximum sustained yield or that which would be economically most efficient.

E) Fundamental Rights

Meeting people's "fundamental rights" to water for drinking and personal use is another basic social objective. Drinking water has the highest priority under the national water policy (Ghosh & Phadtare 1990b, p.434). Although this policy does not have the force of law, supplying water to meet these rights generally receives higher priority than other objectives. From the "fundamental rights" perspective, overdevelopment is occurring when the resource cannot meet basic drinking needs over the long-term.

F) Environment

Environmental maintenance is increasingly being recognised as a key social objective with most natural resources. From the environmental perspective, overdevelopment of groundwater resources can have major implications. Saline intrusion is, for example, common in coastal aquifers subject to heavy pumping. This has had major impacts on agricultural crops in the affected areas. Salinity changes also affect the native plant communities in coastal areas -- particularly mangroves -- and could have important implications for biodiversity. Beyond saline intrusion, groundwater development can cause fundamental changes in regional ecology by lowering water tables below the rooting depth of plants and changing flows in surface streams. Groundwater quality changes through use can also have direct effects on the environment. Agricultural return flows, which are often high in nitrates, other salts and pesticides, can pollute groundwater resources and make them unsuitable for drinking or agricultural uses. In the alluvial aquifers of Gujarat, for example: "The recycling of irrigation water in conjunction with use of chemical fertilisers has further resulted in increased groundwater salinity, making groundwater unsuitable for sustained irrigation in many parts" (High Level Committee 1991, p.16). Maps prepared by the CGWB show nitrate concentrations exceeding 45 mg/l (the maximum acceptable for drinking) in over 370 sample sites scattered across the state (Phadtare 1988). In some cases, such as Ghatlodia near Ahmedabad, they exceed 100 mg/l.[13]

G) Future Options

The maintenance of options for the future is a key social objective. Populations are growing and the economic structure of Indian society is changing. How well groundwater resources are maintained may be a significant factor determining a region's ability to follow different development paths.

Although the importance of maintaining groundwater resources to preserve future development options has not been widely discussed in India, it is a common point of contention in the Western U.S. Many rural areas, for example, find their development options greatly reduced by water transfers out of the area to meet the needs of urban centres. With most of their water claimed by the urban areas, there is no scope for developing even low water intensity industry or agriculture. As a result, the local socioeconomic base is undermined (Weber 1990, Macdonnell & Howe 1986, Checchio 1988, Shupe 1988, Nunn & Ingram 1988, Oggins & Ingram 1990, Woodard 1990). Weber's observations in the case of Crowley County in Colorado could well have been written about India.

> "In an irrigation agriculture economy in a semi-arid environment, it is a truism that a strong and direct relationship exists between the presence of irrigation water and local economic health. ... As the area's economy deteriorates, out-migration causes a further shrinking of the local consumer base, weakening local business opportunities and driving down tax revenues. This negative spiral, once started,

[13] Personal communication, S.C. Sharma 18/6/92.

> increasingly feeds on itself. ... Opportunities to pick up the economic slack by attracting new industries to these water exporting communities is difficult in the extreme. ... Along with changes in the physical and floral environment come changes in the character of life. ... the character of life has been established by agriculture's rhythms. The degree of success achieved in their struggle against a difficult environment determined a family's identity, status, and its life chances. Now with the drying of the lands, the area's reason for being, its history, and its culture lose their meaning. Metaphorically, the people of the area lose their psychological and cultural `roots'. ... For some water exporting areas, it is difficult to imagine a future beyond the present generation." (Weber 1990, quoted in Sax, Abrams and Thompson 1991, pp 233-234)

Whether water scarcity in a region results from transfers, physical depletion of the resource base by water mining or degradation due to pollution, the economic and social effects are likely to be the same. The value of maintaining a viable water resource base simply to maintain future options for economic development often goes unrecognised in the face of current needs.

H) Political Economy

Finally, short term political economic objectives are usually a (if not the) primary factor determining governmental approaches to groundwater development in India. Votes count and handouts that will influence the voters are often a primary objective in development decisions. As Peter Rogers of Harvard University comments in a recent paper with regard to water pricing: "the political economy of tariff setting is extremely important and has to a large extent been neglected by water experts" (Rogers 1993, p.36). Similar comments could be made regarding project design or the structure of a wide range of agricultural subsidies. These factors are recognised at high levels in India. The Report of the Working Group on Major and Medium Irrigation Programme for the Eighth Plan (1990-95) commented, for example, that: "policies on such matters are guided by political expediencies rather than the dictates of financial returns" (GOI 1989a, Chapter XI, p.1).

Clearly, political-economic factors often conflict with basic social objectives in the management of any natural resource. Objective analysis of these factors as part of water management decision making is difficult because the subject tends to be sensitive or "political." These factors are, however, a de facto reality. The political-economic viability of any management recommendation has a large influence over its likely implementation. Analysis of political-economic factors needs to be incorporated in the analysis of groundwater development and responses to emerging overdevelopment problems.

III CRITERIA

The criteria used to evaluate levels of groundwater development depend heavily on the social objectives of primary importance. To date, most attention has been given to volumetric availability criteria. Volumetric availability can, however, be quite misleading in terms of the resource's ability to meet social objectives. As previously noted, it is also hard to measure accurately under the data constraints that exist throughout most of India (Moench 1992). For this reason, it is important to examine the range of possible criteria and their relevance to the different goals identified above.

A) Water Balance

Water balance estimates are the most commonly used criteria for evaluating groundwater resources in India. The ratio of extraction to recharge (E/R) is used as a basis for targeting virtually all government support to groundwater development (GOI 1984). Data collection networks in most states have been designed primarily for the purpose of E/R estimation and most groundwater departments devote the majority of their time and resources to doing that. Despite this, E/R estimates are highly unreliable. Inherent uncertainties in estimation procedures, natural variability and data quality concerns make volumetric estimates problematic when used as the primary guide for resource condition monitoring (Moench 1992).

Water balance criteria are primarily useful in relation to sustained yield and (perhaps) drought buffer and future option maintenance objectives. By themselves, they give very little guidance on the efficiency, equity, or environmental implications of resource use. Furthermore, unless water quality considerations are incorporated, water balance criteria give little indication of the true sustainability of resource utilisation patterns. Although often discussed, incorporating water quality criteria into water balance analyses in a way that gives a realistic guide to resource availability is easier said than done. As a result, volumetric availability criteria are often used by themselves.

B) Water Table Trends

Water table trends in unconfined aquifers are linked to volumetric availability. Long-term declines in unconfined water tables indicate that extraction exceeds recharge. In most cases, particularly in hard-rock regions, specific yield (the amount of water that can be extracted from a unit volume of rock) decreases with depth. As the water table declines, seasonal fluctuations may increase but the actual amount of water it is possible to extract can decline. The additional extraction in early years comes not from recharge, but from mining water stored in the aquifer. Eventually the volume extracted would level off to an amount equal to available recharge.

Water levels can be directly measured in monitoring wells and are, thus, less subject to estimation uncertainties or manipulation than E/R estimates. Data on water levels is also relatively easy to collect and interpret. Water balance estimates require technical competence both to compute and interpret. Water level trends could be measured by villagers in their own wells as well as by official monitoring organisations.

The use of water level criteria has several limitations. First, long-term water level declines generally occur once extraction exceeds recharge. As a result, they give little advance notice of emerging problems (Aiken 1982). Second, the natural variability between fluctuations in individual wells is very high in many areas (particularly hard-rock). High density monitoring networks would be required for local water level declines to become evident. Third, they do not give a comprehensive picture of water availability in relation to social objectives. As with water balance estimates, quality and other considerations need to be incorporated.

Water level criteria are applicable to evaluating resource condition in relation to a larger number of objectives than water balance ones. If water levels are not declining over the long-term, it can generally be assumed that extraction does not exceed sustainable yield and that drought buffers and options for the future are being maintained. Water levels have also some links to equity and economic efficiency. Falling water tables can serve as a preliminary indicator that the poor may be losing access to groundwater resources via their inability to afford well deepening and technology jumps. They may also serve as a preliminary indicator of economic efficiency concerns. Pump efficiency is highly dependent on pumping depth. Efficient energy use requires either a relatively stable water level or technology shifts (new pumps) in response to changed pumping depths. Finally, water levels are a key guide to environmental concerns. High and rising water levels are a primary warning that waterlogging or salinisation may be imminent. Falling water tables serve as an indicator that surface water sources may be affected and that changes in plant access to water (e.g. the regional ecology) could be occurring.

C) Seasonal Fluctuations

The characteristics of seasonal fluctuations in well water levels have not been widely used as a criteria for evaluating groundwater development. They could, however, provide valuable guidance in relation to a number of social objectives particularly in hard-rock areas.

Two characteristics typical of hard-rock aquifers have important implications for interpreting seasonal fluctuations in water levels: 1) storage is mostly confined to the weathered zone near the surface; and 2) specific yield declines with depth. As extraction increases, water levels typically decline over the dry season and then rebound to original levels with the monsoon. In many cases, wells may dry up completely during the non-monsoon period. Because most storage is confined to the weathered zone, well deepening does not provide access to large quantities of additional water.

Under resource estimation procedures recommended by the Groundwater Estimation Committee (GEC) and followed in most states (GOI 1984), the difference between pre- and post-monsoon water levels in monitoring wells are multiplied by the "specific yield" of the rock and the area of the district to estimate monsoon recharge volumes.[14] As water level fluctuations increase, the estimated amount of recharge increases linearly. This is often used as a basis for recommending further groundwater development (Moench 1993). Increasing seasonal fluctuations in water levels are typically described as increasing recharge by "creating" storage space in aquifers. Overdevelopment is generally not regarded as a problem as long as post-monsoon water levels are stable.

Since specific yields typically decline with depth in hard-rock regions, recharge in these areas is not a linear function related just to water level fluctuations. As dry season water levels fall, the amount of fluctuation per unit infiltration will increase. Eventually, wells reach depths where there are few fractures and no "storage space" exists. Very small amounts of recharge would, in this situation, lead to large rises in observed water levels in wells. Essentially, as wells go deeper the amount of fluctuation per unit recharge would increase. If specific yield values based on averages for different lithologies are used -- the approach recommended by the government (GOI 1984) -- then recharge will be overestimated. Due to the fact that specific yield declines with depth, rapid drops in water levels to non-productive depths during the dry season serve as an indication of overdevelopment even where post-monsoon water levels are constant. In this situation, increasing the number of wells could simply increase the rate of water table decline with little or no increase in the actual volumes extracted.

The characteristics of seasonal water level fluctuations could be useful for determining the extent of groundwater development relative to the objectives discussed earlier. Criteria, such as the number of months water tables remain above certain key levels or the depth to which pre-monsoon water levels fall, have equity, economic, environmental, and drought buffer implications. Poor farmers would be progressively excluded from direct access to groundwater for major parts of the year as the water table recedes beyond certain depths (e.g. the depths feasible for dugwells, manual extraction, and centrifugal pumps). Economically, the cost per unit water extracted also increases with depth. Furthermore, in areas where specific yield declines with depth and water table fluctuations are large, investments in new wells may simply increase the rate of seasonal decline with little or no increase in volumes extracted. This could decrease the viability of previous as well as current investments. Environmentally, the amount of time water tables are above certain levels may be a key factor determining the survival of many plant species. Finally, rapid declines to non-productive levels leave little buffer supply in case of drought.

Data availability is an issue in the use of seasonal water table fluctuation criteria. Many states in India collect water level data only twice a year (pre- and post-monsoon). As a result, the development of seasonal water table fluctuation criteria would require new data collection efforts. Some states, such as Tamil Nadu, collect monthly data which could be helpful in evaluating the usefulness of fluctuation characteristics.

[14] For the purpose of these estimates, specific yield is defined as the volume of water that would drain out of a unit volume of saturated rock under the force of gravity.

D) Water Quality

Quality is the primary factor determining the usability of available groundwater in different applications. Development of groundwater resources can affect their quality through several mechanisms. First, freshwater zones are often hydrologically connected to lower quality bodies of water (the ocean or saline aquifers). Overextraction in freshwater areas can change the hydrostatic balance causing migration of low quality water into previously fresh areas. Second, water quality in shallow aquifers often declines as use intensity increases. Evaporation, leaching of salts from the soil, fertiliser and pesticide applications, and so on all serve to decrease the quality of water reinfiltrating into aquifers. Third, water quality often declines with depth as progressively older waters are tapped.

Water quality criteria are used, to some extent, in current approaches to estimating volumetric availability in that recharge to saline groundwater areas is not included in availability estimates. Quality data are, however, often unavailable. Even where collected, they are rarely published in conjunction with volumetric availability estimates.

Detailed water quality data could act as a key guide to groundwater availability in relation to different social objectives. Water quality trends often have implications for the sustainability of current use patterns, use economics, environmental impacts, the drought buffer characteristics, and the maintenance of future use options. The appropriateness of different water quality criteria depends heavily on projected uses. As a result, basic chemical data on water quality need to be collected and made readily available. If baseline data are generally available, water quality levels and trends can be evaluated in relation to local conditions and the full range of objectives.

Overall, water quality criteria must be given equal weight to indicators of volumetric availability in evaluating groundwater development levels.

E) Extraction Economics

Economically, overdevelopment of groundwater resources is occurring when the costs associated with extraction (including the value of the resource in place) exceed the benefits. From this perspective, groundwater in many sections of India may already be heavily overdeveloped. A large number of subsidies (from free electricity to government support for well development financing) warp the economics of groundwater extraction and use. Farmers in Mehsana District, for example, irrigate wheat using wells drilled to depths of up to 1200 ft and 50 plus horsepower pumps. If the full costs of extraction were calculated they would probably far exceed the value of the wheat grown.

Ideally, the full social costs of current extraction including such intangibles as foregone future opportunities, environmental values, and the insurance value of drought buffer maintenance should be compared to the benefits derived from current extraction. Social cost benefit analyses tend, however, to be time consuming and relatively subjective. Detailed economic studies focusing on the direct costs of extraction (well capital, unsubsidised energy, and well maintenance costs) and the direct benefits of extraction (crop production), could provide more specific criteria for evaluating the extent of groundwater development. On a more crude level, the financial viability of wells is a key indicator of groundwater conditions. If a large proportion of new wells are failing (going dry or giving too little yield for the purpose intended) before users can repay development loans, then the resource is overdeveloped. Relatively simple measures (well failure rates, yields, loan repayment rates, etc.) could be developed as financial criteria for guiding groundwater development financing.

F) Stock Maintenance

Maintenance of groundwater stocks could be a useful criteria for measuring overdevelopment relative to drought buffer, fundamental rights, and future option objectives. The key idea would be to identify a "minimum strategic reserve" of good quality groundwater in each area equivalent to the amount estimated as necessary to meet long-term objectives. Overdevelopment would be occurring if normal use began to reduce the quantity or quality of buffer stocks.

G) Environmental Effects

Evaluation of groundwater development levels relative to environmental objectives would depend heavily on the environments of concern. The direct environmental effects of groundwater development are likely to be minimal in arid areas where the natural water table is very deep. Effects are likely to be much larger where groundwater is the primary dry-season source of water for surface springs and streams. In this case, effects on springs and stream baseflow, although difficult to document, would be key indicators of overdevelopment. Sensitive species could be monitored for groundwater development effects where environmentally valuable environments (such as wetlands or mangroves) are dependent on water table levels or groundwater quality. The environmental effects of groundwater development could be particularly large in areas where natural water tables are shallow and groundwater is reused multiple times. In this case, quality changes related to development and re-use (typically increasing salinity) could have major environmental impacts. In some cases, salinisation can be a direct result of heavy dependence on and reuse of groundwater. Overall, the specific environmental criteria used to monitor groundwater development need to reflect local conditions. In many cases they would probably overlap with the quality and water level criteria discussed earlier.

IV THE ISSUE OF MINING

The question of groundwater mining in low recharge areas has received very little attention so far in India. Available data suggest, however, that recharge rates may be very low, particularly in arid sections of northwestern Gujarat and Rajasthan. Apparent dates on water samples from deep aquifers in central Gujarat are roughly 500 years (Bhattacharya et al. 1979). These aquifers are recharged primary by leakage from the upper sections (CGWB 1984). Extraction from most of them is large and water levels are falling. Recharge studies based on moisture profiles and tritium (both environmental and using applied tracers) suggest recharge rates on the order of 5-14% of rainfall, far lower than the 20-25% of rainfall generally assumed for similar soils in official groundwater recharge estimates (Sukhija 1979, Gupta & Sharma 1987, GOI 1984). Despite optimistic official estimates, on a human time scale, water in these aquifers is essentially a nonrenewable resource.

Management of aquifers in areas with negligible recharge requires a fundamentally different approach from areas where resources can be treated as renewable. The questions of sustainability and maximum yield are, in these areas, irrelevant. Any significant use will ultimately lead to depletion. As a result, how groundwater is used and for whose benefit is much more critical than in cases where the resource is regularly renewed. Managing depletion to meet social objectives is the central issue.

Where recharge is minimal, the nonrenewable nature of the resource intensifies the need to explicitly identify those management objectives of greatest importance. Uncontrolled development can permanently damage the resource's ability to serve as a buffer against drought or meet fundamental rights to drinking water. If use patterns are inefficient then a large part of the resource's value can be lost with little benefit generated. Tradeoffs between management objectives are also intensified where groundwater is a nonrenewable resource. Policies designed to increase immediate production and access equity (such as well development and energy subsidies) generally increase the rate at which stocks are depleted and decrease use efficiency. On the other hand, regulations designed to protect resource stocks (well spacing, restrictions on extraction, etc.) may allow limited sections of society to monopolise the entire resource stock.

Overall, the nonrenewable nature of some groundwater resources needs to be recognised. Scientific work is required to delineate which resources are best treated as nonrenewable. Policy and management decisions are essential if larger social objectives are to be incorporated in the way development occurs.

V CONCLUSION

Groundwater development in India over the past four decades has been rapid and uncontrolled. Although the true extent of development relative to available resources is unknown, signs of overdevelopment are increasingly evident. Management, rather than development, is the fundamental need.

As long as groundwater resources could be viewed as extensive and undeveloped, there was little requirement to recognise or debate the social tradeoffs that come with scarcity. With the emergence of problems associated with overdevelopment, differing social objectives are increasingly expressed. Unfortunately, both clear statements of social objectives and the basic data necessary to evaluate groundwater conditions in relation to them are lacking. As a result, much of the debate over groundwater development is anecdotal or based on the results of site specific case studies.

When initiated over two decades ago, groundwater data collection systems were designed to guide development finances to areas with large potential resources. The implicit goal was to maximise yields within sustainable limits (e.g. increase extraction until it equalled recharge). Recharge and extraction estimates based, primarily, on water level fluctuations and well census data have been the primary criteria used to evaluate groundwater conditions in relation to sustained yield goals. Economic efficiency, equity, environmental, drought buffer, future option maintenance, and the provision of drinking water as a fundamental right are now increasingly expressed as basic social goals that should guide groundwater development and management. A clearly defined set of criteria against which groundwater resource condition can be evaluated in relation to these goals is essential if the debate over groundwater development is to become less anecdotal.

This paper has been a preliminary attempt to list the different social goals in groundwater development and to suggest a set of criteria against which development levels can be measured.

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OVEREXPLOITATION OF GROUNDWATER RESOURCE - EXPERIENCES FROM TAMIL NADU

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Abstract

The increasing demand for irrigated acreage is rendering water an exceedingly scarce resource. Well irrigation plays a major role in Indian agriculture for a variety of reasons such as (i) decreasing scope for and increasing cost of surface irrigation development, (ii) the increasing demand for more controllable water supply created by the HYV technology, and (iii) low private investment on groundwater development in contrast to the huge public outlay on surface irrigation, etc.

In Tamil Nadu, which stands in the forefront of modern commercialised agriculture, the growth of well irrigation has been tremendous in the past three decades. The number of wells increased from 9 lakh in 1960-61 to as high as 17.44 lakh in 1988-89 in the state, and the area irrigated by wells increased from 5,94,300 ha to 11,68,570 ha during this period. The relative share of wells in the net irrigated area by all sources increased from about 24 percent to more than 41 percent, while that of tanks decreased from 38 to 21 percent and that of canals decreased from 36 percent in 1960-61 to 32 percent in 1988-89. In Coimbatore district of Tamil Nadu, which is known for its abundance of wells, farmers continue to install new wells despite overdevelopment of groundwater and the commissioning of three new major surface irrigation projects. This has resulted in the overexploitation of groundwater and declining groundwater table in many parts of the district.

This paper attempts to discuss the nature of groundwater exploitation and some of the immediate consequences of overexploitation. The authors describe the topography and rainfall of Coimbatore District and related this to the past and present status of groundwater. They find a strong, significant statistical relationship between number of wells and water levels over time. They find several immediate consequences of overextraction, including the need to deepen or abandon wells, changes necessitated in cropping patterns, reduction of irrigated area, and abandonment of agricultural lands.

1. INTRODUCTION

Water scarcity is increasing due to the growing demand for irrigation, particularly from groundwater sources. Well irrigation plays a dominant role in Indian agriculture for a variety of reasons including: (i) decreasing scope for and increasing cost of surface irrigation development, (ii) the increasing demand for more controllable water supply, created by the

HYV technology, and (3) low private investment in groundwater development in contrast to the huge public outlay on surface irrigation. In Tamil Nadu, which stands in the forefront of modern commercialised agriculture, the growth of well irrigation has been tremendous in the past three decades. The number of wells has increased from 9 lakh[15] in 1960-61 to as high as 17.44 lakh in 1988-89 in the state, and the area irrigated by wells has increased from 5,94,300 ha to 11,68,570 ha during this period. The relative share of wells in the net irrigated area by all sources has increased from about 24% to more than 41%, while that of tanks decreased from 38% to 21% and that of canals decreased from 36% in 1960-61 to 32% in 1988-89. In Coimbatore district of Tamil Nadu, which is known for its dominance of well irrigated agriculture, the growth in the number of wells continued unabated in spite of overdevelopment of groundwater and commissioning of three new major surface irrigation projects. This has resulted in declining groundwater tables in many parts of the district. This paper attempts to discuss the nature of groundwater exploitation and some of the immediate consequences of overexploitation.

2. GROUNDWATER OVEREXPLOITATION: AN OVERVIEW

Parts of Coimbatore District are characterised by an exceedingly rapid fall of the groundwater table. In some areas, the water table has fallen nearly 200 feet during the past 20 years. Farmers are still deepening their wells to maintain at least a portion of their cropland under irrigation. This phenomenon was apparently caused by great cost reductions in water use associated with the change from lifting water with animal power to use of electricity. Hence, a system which may have been in equilibrium with a relatively high water table using traditional agricultural methods has become unstable when new technology was adopted.

Though few financial institutions such as NABARD are insisting on a minimum distance between wells as a precondition for getting institutional credit, there have been no serious constraints to drilling of new wells or the deepening of old ones. The following explanations may be helpful for further conceptualising the overexploitation problem[16].

Assuming that there is only one individual, "A", pumping from one groundwater reservoir and as long as "A's" pumping has no effect on the groundwater table, "A" will equate the marginal factor cost (MFC) of the water with the marginal value product (MVP) of the water. The MVP curve is likely to be declining, while the MFC is likely to be constant (Fig 1). Further, because of the improved lifting technology adopted, the marginal factor cost of water has declined considerably. The optimal level of water use would therefore shift to the right and at this stage, the rate of water withdrawal exceeds the rate of recharge, and the water table declines.

[15] 1 lakh = 100,000

[16]* The discussions benefitted from the note, "Some Thoughts on the Coimbatore District Ground Water Problem", by H.H.Stoevener, Department of Ag.Economics, Tamilnadu Agricultural University, Coimbatore, 1976.

In case the water table does not drop, then X' represents the maximum amount of water which would be withdrawn. Pumping any quantity of water greater than X' would require deepening so as to continue the pumping operation and necessarily the pumping costs will increase, which is indicated in Fig. 2 by the increasing portion of the MFC function to the right of X'(MFCa). This indicates the increase in cost of water required to maintain the productivity of the well. It is assumed that the rate of recharge of the groundwater reservoir increases as the height of the water table declines. Hence, the maximum quantity of water which can be withdrawn from the reservoir without reducing the water table further is greater when the water table is lower (the well is deeper) than when it is higher. Note that in the absence of this assumption, the MFC function would rise to infinity at X' and it would never be attractive to pump more than X'. Under this assumption, the optimal water use would be at Y.

If there is a second individual, "B", pumping from the same groundwater aquifer (Fig. 3) "A's" MVP curve remains as before but the maximum withdrawal level (X') now occurs at a lower level of water use than it did before, to reflect "B's" withdrawal of water from the same pool. MFC rises to the right of X'. From "A's" point of view, Y' is the equilibrium quantity of water to be used.

As "A" uses greater quantities of water than X' the water table falls not only for him, but it also affects "B." Hence, from a social standpoint MFCa understates the costs of "A's" water use. MFCs might be the relevant function, where the difference between MFCs and MFCa represents the additional costs which "A" imposes on "B" by increasing his water use beyond X'. In this case Z'

would represent the social optimal level of water use for "A" or Y'Z' is the quantity of water in excess of the social optimum used by "A." It should be noted that "A's" pumping at X' causes the adjustment cost to be borne by "B." For simplicity it is assumed here that "B" would adjust by deepening his well to maintain approximately the same level of water use. It is possible that "B" has another lower cost adjustment such as reducing the quantity of water used. Only if "B's" demand for water is perfectly inelastic with respect to price would he attempt to maintain exactly the same level of water use.

The increase in marginal costs (MFC' to the right of X') is due to costs of deepening the well -- which of course is a sunk cost -- and due to increased costs of pumping water (MFCp) from a greater depth. The equilibrium level of water used is R'. However, because of competition over-pumping occurs and if "A" is pumping less than R', there is no guarantee that "B" will not pump the water saved by "A." Under this process water table further declines. An equilibrium will be possible as water use declines in accordance with continuous counter-clockwise rotation of the MFC functions and as marginal water users cease production entirely. The equilibrium will be characterised by a much lower level of water use at a much higher cost. It is also likely that the remaining water use would be

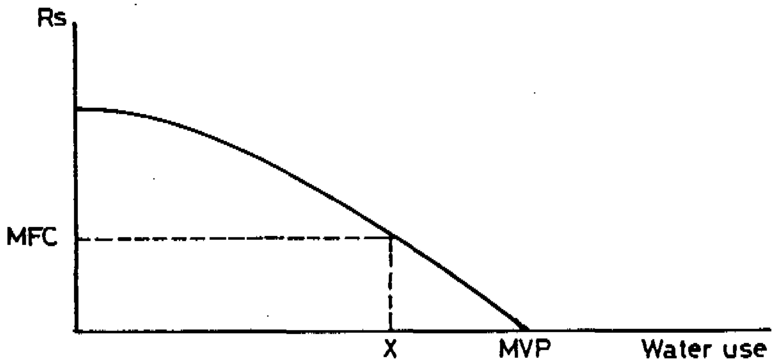


FIG. 1 PUMPING WITH EXISTING TECHNOLOGY

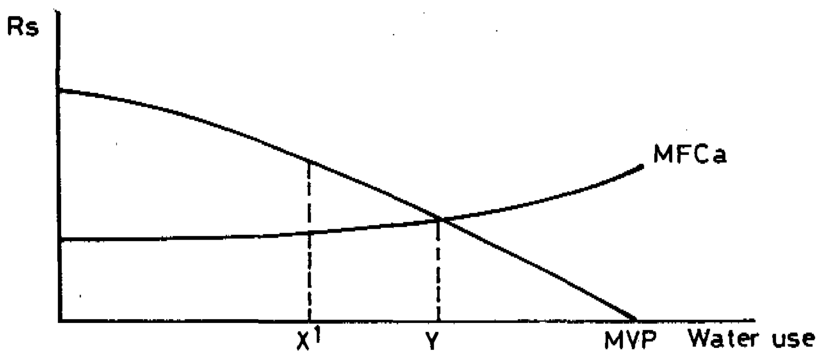
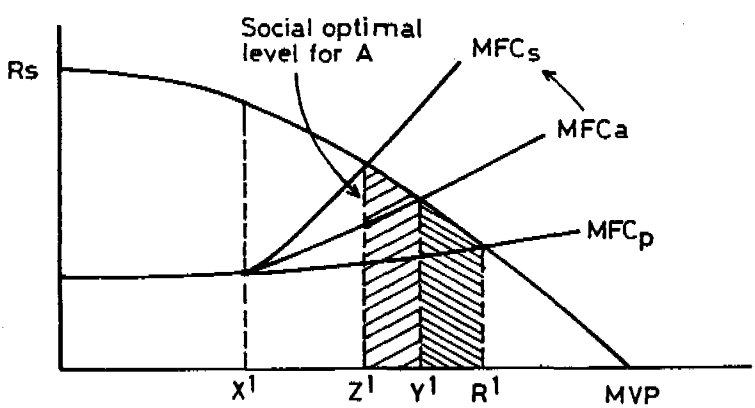


FIG. 2 PUMPING WITH MODERN TECHNOLOGY



Y^1 = Equilbrium before deepening
R^1 = Equilbrium after deepening

FIG. 3 MORE FARMERS PUMPING WITH MODERN TECHNOLOGY concentrated in the hands of few farmers, those who are relatively well off initially to afford the investments necessary to maintain the productivity of their wells.

3. COIMBATORE DISTRICT : A SCENARIO

a. Topography: Coimbatore district encompasses an area of 15678 sq km of plains with altitudes ranging between 200 and 400 m above MSL. To the west and south, plains give way to mountain regions which in places rise to more than 2000 metres above MSL. The mountains form a rain shadow area over the plains which consequently have a dry climate. Geologically Coimbatore district is composed mainly of a primary rock plateau consisting of gneiss and granite.

b. Rainfall: The average annual rainfall of Coimbatore district for the past 100 years had been 715 mm. When the total rainfall was plotted against the time there were wider variations from the mean. Using Fourier Analysis for 36 years of rainfall data (1950-51 to 1985-86), Swaminathan and Kandasamy (1991) found that rainfall in this district has 8 to 10 years of cyclical variation and that the low R^2 value of 0.0011 indicated that the dependability of the rainfall was very less.

4. PAST AND PRESENT STATUS OF GROUNDWATER DEVELOPMENT IN THE DISTRICT

Even though this district is known for its groundwater overexploitation during the recent times, well irrigation has long been predominant in this district. Baker (1984) cites a tripling of the number of wells in Coimbatore district from approximately 20,000 to 65,000 during the nineteenth century, "to the point where there was roughly one well per cultivator". The same momentum of growth in well irrigation continued in this century. This is illustrated by the fact that the number of wells in the year 1989-90 was about 1,94,926 as against about 65,000 wells in the beginning of the century. In spite of tremendous increase in the number of wells, during the last 30 years, the net area irrigated by wells has increased only marginally from about 1,41,655 ha to 1,42,096 ha during the same period. As a result the average net area irrigated per well has shown a 50 % decline from 1.56 ha in 1960-61 to about 0.747 ha in 1989-90 (Table 2). The tremendous increase in the number of wells and the stagnation in the net area irrigated during the last 30 years might be due to two important reasons: (a) the increased number of wells might have simply shared the command area of already existing wells, thus resulting in a more equitable distribution of scarce groundwater resource among the farmers of this district, or (b) the stagnation in NIA by wells might have been due to the fall in the groundwater table, and a shift in cropping pattern.

Table 1. Basic Details on Irrigation in Coimbatore and Salem Districts

District	NSA (ha)	GIA (ha)			No. of Wells	Well Density(No./ sq km)	No. of Wells Per Cultivator	Average GIA Per Well (ha)	Rainfall (mm)
		Canal	Well	Others					
Coimbatore	654329	122047	166661	7493	200229	12.77	0.36	0.83	647.2
(undivided)			(41.20)		(56.27)		(2.53)		
Salem	447822	21243	110951	2188	228686	26.44	0.48	0.49	841.5
		(15.63)	(81.62)	(2.75)					

To have a comparative picture of overexploitation of groundwater, Salem district where groundwater mining is less pronounced was also included in the study. The basic details on irrigation sources in these two districts are provided in Table 1. The data indicates that well density in Salem district was more than twice that in Coimbatore. While wells serve a little over 56 % of the gross irrigated area in Coimbatore, the corresponding figure for Salem district was much higher at 81.60 %. The higher number of wells in Salem district might have been due to two reasons: a) absence of alternative sources of irrigation in Salem district in contrast to Coimbatore where three major surface irrigation projects irrigate about 41.20 % of gross irrigated area, b) higher rainfall in Salem district leading to lower probability of well failures, thus encouraging digging of more and more new wells.

Table 2. Stage of Groundwater Development in Selected Blocks of Coimbatore (recharge/draft in ha m)

Sr. No.	Block	1985			1992		
		Utilisable Recharge	Net Draft	Stage of Development	Utilisable Recharge	Net Draft	Stage of Development
1.	Pongalur	3396	2253	66	3420	5077	148
2.	Sulur	2556	2339	92	2344	2895	123
3.	Tiruppur	1737	1658	95	2443	3005	123
4.	Annur	9482	8176	86	3442	4031	117
5.	Avinashi	5018	4904	98	4448	4600	103
6.	Madukkarai	2972	2230	75	3133	3207	102
7.	Palladam	8184	8111	99	2489	4612	185
8.	Sultanpet	2661	2259	85	2474	4174	169
9.	Modakkurichi	5639	3269	58	8687	9717	112
10.	T.N.Palayam	5705	2098	37	4329	4892	113
11.	Nambiyur	2978	2886	97	4251	4584	108
12.	Andhiyur	3512	3391	97	2660	3980	150
13.	Bhavanisagar	8341	2325	28	1875	2904	155
14.	Kodumudi	5943	5783	97	2913	4496	154
Coimbatore Dist.		211199	150674	71	184819	159947	87

Table 3. Stage of Groundwater Development in Selected Blocks of Salem District (recharge/draft in ha cm)

Sr. No.	Blocks	1985 Utilisable Recharge	1985 Net Draft	1985 Stage of Development	1992 Utilisable Recharge	1992 Net Draft	1992 Stage of Development
1.	Konganapuram	1397	1325	95	2548	2728	107
2.	Mallasamudram	2379	2235	94	3511	3685	105
3.	P.Velur	3199	2579	81	7859	8441	107
4.	Attur	8864	6212	70	3525	4082	115
5.	Rasipupuram	1993	2060	103	2622	2799	107
6.	P.N.palayam	6617	4816	73	4570	4664	102
7.	Erumaipatti	6411	3063	48	3624	5314	163
8.	Namagiripettai	3125	3113	100	3195	8155	255
9.	Vennandur	12903	12373	96	2705	3641	135
	Salem dist.	150165	103333	69	147620	123514	84

5. GROUNDWATER RECHARGE AND EXTRACTION

A comparative picture of the stage of groundwater development in selected blocks of Coimbatore and Salem districts is presented in Tables 2 and 3 for two periods - 1985 and 1992. The data for Coimbatore district indicates sweeping changes in the level of groundwater development within a period of seven years. In more than one-third (14) of the total number of 41 blocks, the groundwater extraction exceeds recharge. This results in overdraft of water ranging from 74 ha m in Madukkarai block to 2127 ha m in Palladam taluka, where the groundwater development was as high as 185%. Even among the rest of the 27 blocks, groundwater development has exceeded 70% of recharge except in two hill blocks. Overall, groundwater development in the district has increased from 71.34% in 1985 to 86.54% in 1992.

In Salem district out of the total number of 35 blocks, 9 blocks reported overdraft of groundwater above the annual utilisable recharge (Table 3) in the year 1992 as compared to only 2 blocks in the year 1985. In one of the blocks (Namagiripettai) the overdraft was as high as 255 percent. The level of groundwater development at district level has increased from 69% in 1985 to 84% in 1992.

The total number of white (stage of groundwater development less than 65%) , grey (65-85%), and dark (> 85%) blocks in these two districts is presented in Table 4. Even though the number of dark category blocks were almost equal in both the districts in 1992, the total number of gray and dark blocks were about 36 in Coimbatore while it was only 26 in Salem district. The number of blocks which shifted between different categories are presented in Table 5, which indicate that Coimbatore district has recorded a higher net forward shift of 8 blocks (i.e. white to gray, gray to dark, or white to dark) when compared to Salem district where 6 blocks have shifted in the forward direction.

Table 4. Number of Blocks with Different Stages of Groundwater in Coimbatore and Salem Districts

District	Year	White (<65% extraction)	Grey (65-85% extraction)	Dark (>85% extraction)
Coimbatore	1985	16	11	14
	1992	5	19	17
Salem	1985	14	10	11
	1992	9	10	16

Table 5. Number of Blocks Shifted between White, Grey, and Dark Categories from 1985 to 1992

S.No District	Shift From	To	Number
1. Coimbatore	White	Grey	7
	Grey	Dark	3
	White	Dark	4
	Dark	Grey	5
	Dark	White	0
	Grey	White	1
2. Salem	White	Grey	3
	Grey	Dark	4
	White	Dark	4
	Dark	Grey	3
	Dark	White	0
	Grey	White	2

The factors affecting groundwater recharge and extraction in Coimbatore district were analysed using data on depth to water table, rainfall, and number of wells, for a period of 20 years from 1972 to 1992. Data on monthly water table fluctuations collected from about 75 control wells were obtained from the Ground Water Division of the Public Works Department, and the annual mean water table was worked out. The following regression model was fitted using the Ordinary Least Squares method:

Dwtab=	7.0435	0.0173 Lagrain +	0.0959 Lagwell
		(5.20)	(4.094)

N = 20; R-squared = 0.7178; F-ration = 20.353

Dwtab =	depth to water table below ground level in metres,
Lagrain =	mean of rainfall lagged 1 and 2 years, in mm (e.g. for 1992, the mean of rainfall in 1990 and 1991 was taken)
Lagwell=	number of wells in the district lagged 1 year, in thousands

Figures in parentheses are t_ratios. ** indicates significance at 1% level.

The results indicate that the variables have expected signs and are significant at 0.01 probability level. An increase in the lagged mean rainfall by 10 mm brings up the water table by 0.17 metre (i.e. decreases the depth to water table by 0.17 metre) and an increase in number of wells by one thousand increases the depth to water table (i.e. pushes down the water table) by about 0.10 metre. The increase in depth to water table due to increase in number of wells is an indirect effect caused by the sharing of aquifers that have limited supply of water among increasing number of wells. This analysis was not done for Salem district due to non-availability of data.

6. CONSEQUENCES OF OVEREXPLOITATION OF GROUNDWATER

Some of the immediate consequences of overextraction of groundwater are: a) fall in water table forcing farmers either to deepen their well or to abandon it depending upon the accessibility of financial resources, b) change in cropping pattern, c) reduced area under well irrigation, and d) abandoning agriculture itself and becoming an agricultural or non-agricultural labourer.

Falls in water table in selected talukas of Coimbatore district was analysed using monthly water table data collected from control wells. The range of water table fluctuation in three different periods is presented in Table 6. The mean water table is found to have declined significantly in all the talukas of the district during these years. Avanashi taluka has recorded the maximum reduction of about 8.52 metre (from 10.42 m to 18.94 m), followed by Coimbatore (4.48 m), Palladam (4.25 m), Pollachi (3.91 m) and Udumalpet taluka (2.70 m). The steep fall in water table in the first two talukas is due to the absence of surface irrigation sources, while the remaining three talukas which reported a less serious fall in water levels have surface irrigation sources which recharge the wells. The mean reduction in water table at district level was about 4.77 m (from 9.03 m to 13.80 m). The intra-year fluctuation in water table was also higher in the district, which was about 6 metres in a year.

Table 6. Groundwater Table Fluctuation in Coimbatore District (in metres below G.L.)

Sr. No. Taluka	1972 Max	Min	Mean	1992 Max	Min	Mean	Difference Between Water Table in 1972 & 1992
1. Avanashi	15.09	6.05	10.42	22.71	14.65	18.94	8.52
2. Coimbatore	16.24	11.49	13.72	20.36	13.94	18.20	4.48
3. Palladam	11.48	7.80	10.01	15.62	11.25	14.26	4.25
4. Pollachi	7.62	4.02	6.22	11.97	5.79	10.13	3.91
5. Udumalpet	6.67	3.18	4.78	9.56	4.44	7.48	2.70
District mean	11.42	6.51	9.03	16.04	10.01	13.80	4.77

Deepening of wells, which leads to additional financial burden on farmers, was studied in both Coimbatore and Salem districts. Data presented in Table 7 indicates that farmers deepened their wells five times on an average in Coimbatore, and 3 times in Salem. The extent of deepening was 14.60 m in Coimbatore and 6.80 m in Salem.

Table 7. Particulars of Wells in Coimbatore and Salem Districts

District	Initial Depth of Well (m)	Initial Cost of Digging	Number of Deepening (m)	Extent of Deepening	Cost of deepening	% of Cost of Deepening to the Cost of Digging
Coimbatore	12.75	8625.00	5.00	14.60	26250.00	304
Salem	11.00	8000.00	3.00	6.80	15750.00	197

Deepening a dug well involves huge investments, often exceeding the cost of initial digging of the well itself. The average cost of deepening ranged from Rs.15750 to Rs.26250 per well. Cost of deepening to the initial cost of digging was as high as 304% in Coimbatore. Since deepening is mainly done by horizontal or vertical boring inside the existing open wells, it creates a new class of wells called dug-cum-bore wells. The extensive practice of deepening through boring could also be understood by the fact that Coimbatore district has more than one-third (2775) of the total number of dug-cum-bore wells (7522) in the state as a whole.

As deepening involves huge investments, farmers with financial constraints and those who are risk-averse tend to abandon wells, if they fail. This has resulted in a steep rise in the number of wells abandoned in the district (from 4033 in 1960 to about 16,700 in 1990), in contrast to less than doubling in the number of wells in use in the district. Such a large number of wells going out of use results in the large amount of capital invested in their construction going to waste. Even at a conservative assumption of Rs. 40,000 per well, the wasted investment due to abandoning of 16,700 wells works out to Rs.67 crores.[17]

Thirdly, the increasing number of wells and declining water table have resulted in stagnation of the net area irrigated by wells. Hence, the net area irrigated per well has decreased sharply over the years. To identify the factors influencing area irrigated per well the following form of regression equation was estimated:

Apwell = Constant + b (lagrain) + c (lagwell)

where,

Apwell = Net area irrigated per well in the district, in hectares,
Lagrain = Mean rainfall lagged by 1 and 2 years, in mm.
Lagwell= Density of wells defined as the ratio of total number of wells in the district to the geographical area of the district, lagged by 1 year, and b and c are parameters to be estimated.

The results of the regression are presented in Table 8. A comparison of the results for Coimbatore and Salem districts shows that the influence of both rainfall and density of wells on area irrigated per well were higher in Coimbatore district than in Salem district. In Coimbatore district, every 1 cm increase in rainfall increases the net irrigated area per well by 0.0076 ha, while in Salem district it was only 0.0038 ha which is only 50% of the former. This might be due to the fact that the variation in rainfall was higher in Coimbatore district (co-efficient of variation for the last 30 years was 16.48) than that in Salem district where the coefficient of variation was only 11.62 %. Similarly, the impact of density of wells on area irrigated per well was much higher in Combatore district than that in Salem district. While every additional well per square kilometre of Coimbatore caused a decrease in the NIA per well by 0.11 ha, the corresponding figure for Salem district was only about 0.031 ha.

[17]1 crore = 10,000,000

Table 8. Comparison of Factors Influencing Area Irrigated Per Well in Coimbatore and Salem Districts

Sr. No.	District	Factors	Regression Coefficient	T-value	R-squared	F-ratio
1.	Coimbatore	Lagged mean rain(cm)	0.0076	3.655	0.7627	43.4
		Lagged well density (no./sq km)	-0.1083	8.971		
2.	Salem	Lagged mean rain(cm)	0.0038	2.142	0.7057	26.38
		Lagged well density (no./sq km)	-0.0306	7.196		

The negative coefficient for intensity of wells indicates a clear case of externality caused by digging additional wells in both the districts, even though the externality was much higher in Coimbatore district than in Salem district. To offset the externality caused by digging each additional well, it requires an additional rainfall of about 14.30 cm above the mean rainfall in Coimbatore district and 8.00 cm above the mean rainfall in Salem district.

The other major consequences of fall in groundwater table are changes in cropping pattern, decreases in the area under well irrigation, migration, etc. These effects were studied in both the districts by selecting a sample of 100 farmers whose lands were irrigated only by wells. The results are presented in Tables 9 through 12. The data on cropping pattern indicates that even though the share of irrigated crops to total area was little higher in the past (85.23% as compared to 83.03% in Salem district), the present share of irrigated crops in Coimbatore district is found to be much less at 39.58% as compared to 62.50% in Salem district. In spite of the sharp decline in the share of highly water intensive crops like paddy and sugarcane in Salem district, tapioca became the major irrigated crop due to the predominance of tapioca-based industries in Salem.

Table 9. Cropping Pattern in Well Irrigated Areas of Coimbatore District (areas in ha)

Crops	1970		1993	
	Area	% to total	Area	% to total
Rainfed:				
a. Sorghum	0.12	6.94	0.53	29.95
b. Ragi	0.05	2.76	0.14	7.85
c. Cotton	0.09	5.07	0.38	21.66
d. Maize	-	-	0.02	0.96
	0.26	14.77	1.06	60.42
Irrigated:				
a. Sugarcane	1.06	60.36	0.28	15.67
b. Vegetables	0.06	3.22	0.04	2.26
c. Maize	-	-	0.15	8.75
d. Cotton	0.03	1.84	0.14	7.83
e. Turmeric	0.29	16.59	0.09	5.07
f. Paddy	0.06	3.22	-	-
	1.50	85.23	0.70	39.58
Total	1.76	100.00	1.76	100.00

Table 10. Cropping Pattern in Well Irrigated Areas of Salem District (area in ha)

Crops	1970		1993	
	Area	% to total	Area	% to total
Rainfed:				
a. Sorghum	0.22	9.82	0.45	19.64
b. Bajra	-	-	0.06	2.68
c. Maize	0.10	4.46	0.08	3.57
d. Cotton	0.06	2.69	0.26	11.60
	0.38	16.96	0.85	37.50
Irrigated:				
a. Paddy	0.75	33.04	0.14	6.25
b. Sugarcane	0.67	29.46	0.18	8.04
c. Tapioca	0.38	16.96	0.69	30.36
d. Turmeric	0.08	3.57	0.28	12.50
e. Cotton	-	-	0.12	5.36
	1.88	83.03	1.42	62.50
	2.27	100.00	2.27	100.00

Out of the total number of 100 farms surveyed in each district, the number of wells abandoned is higher in Coimbatore district (20 %)than in Salem district (11 %), and the number of farmers who migrated is almost 3 times higher in Coimbatore as compared to Salem district. The number of farmers with off-farm employment is a very common phenomenon in both the districts (Table 11).

Table 11. Details of Abandoning Wells, Migration and Off-farm Employment

District	No. of Farms Surveyed	No.of Wells Abandoned	No.of Farmers Continuing Agriculture	No.of Farmers Migrated	No.of Farmers Engaged in Off-farm Employment
Coimbatore	100	20	92	8	79
Salem	100	14	97	3	84

The data on wells in Table 12 indicates that the average horsepower of pumpsets in Coimbatore district range from 9.38 in open wells to 11.25 in borewells, while this range was 8.50 to 9.38 hp in Salem district. The average number of hours of pumping was little higher in the case of borewells in Salem district at a much lesser depth than in Coimbatore district. Head of water in the wells of Coimbatore district was at a much higher depth resulting in lower discharge of water even with high powered pumpsets.

Table 12. Particulars of Well-water Pumping in Coimbatore and Salem Districts

District	Type of Well	Average Depth of Well	Average Horse-power	Average Hours of Pumping Per Day	Head of Water (m)	Discharge (lps)
Coimbatore	Open well	26.63	9.38	2.50	25.16	111.83
	Bore well	123.50	11.25	8.50	112.50	102.58
Salem	Open well	13.88	8.50	2.25	12.00	174.60
	Bore well	96.35	9.38	9.50	81.38	136.53

7. CONCLUSIONS

In spite of the commissioning of three major surface irrigation projects with a share of about 40% of the gross area irrigated, the number of wells continued to grow in Coimbatore district during the last 30 years. However, this has not resulted in any significant increase in the gross area irrigated by wells, which has stagnated around 1,50,000 ha. This indicates that the new wells have just shared the command area of existing wells, thus resulting in a more equitable distribution of scarce groundwater resource. At the same time, this has resulted in a steep fall in groundwater table. Even though the density of wells in Salem district was more than twice that of Coimbatore it has not resulted in such a serious problem of overexploitation as in Coimbatore. This is possibly due to higher rainfall and lesser depth of wells in Salem. Both rainfall and well density were found to have a less impact on area irrigated per well in Salem district as compared to Coimbatore. This leads us to the conclusion that the equilibrium of water table is more stable when wells are not much deeper and the water table is also higher. However, this is only a preliminary conclusion and needs to be further examined in the light of more hydrogeological information. Since well density as well as depth of wells influence the overexploitation of groundwater resource, future policies should aim at implementing spacing norms. To augment recharge, it is also warranted to initiate measures such as artificial recharge of aquifers and appropriate electricity pricing norms to control excess pumping.

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EMERGING PROBLEMS, OPTIONS AND STRATEGIES IN THE DEVELOPMENT AND MANAGEMENT OF GROUND WATER RESOURCES IN INDIA

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Abstract

India contains a wide diversity of hydrogeological settings. The utilisable groundwater resource in the country has been assessed as 45.34 million ha m per year and the current level of groundwater development is about 30% of the amount available for irrigation. Groundwater development is not, however, uniform all over the country. In a number of areas, intensive groundwater development has led to rather critical situations and the emergence of problems like declining water levels, shortage in supply and saline water encroachment, etc. The need for in-depth analysis of problems that have emerged due to extensive development of groundwater in certain areas is emphasised in this paper.

Groundwater development in hard-rock areas faces many uncertainties including variability in rock type and its capacity to hold and transmit water. This paper stresses the need for artificial recharge and conservation of groundwater in these areas. At the same time, limitations are present on the scope for large scale recharge due to heterogeneous nature and noncontinuity of hard-rock aquifers. Options for effective use of available groundwater in these low potential areas are discussed in the paper.

Where coastal areas are concerned, the need to precisely understand the hydrogeological environment in order to evolve an operating mechanism for controlled groundwater withdrawal that does not upset the hydrochemical and hydrodynamic balance is emphasised in the paper. In canal command areas where the problem of waterlogging is prevalent, the need to adopt conjunctive use of surface and groundwater which combines the advantages of groundwater storage with surface water system and serves as both a remedial and corrective measure for preventing waterlogging and for efficient use and management of water resources is emphasised.

The existing legal measures and indirect controls on the groundwater development in the country are briefly mentioned in the paper. The need for a thorough review of all aspects involved in the development or groundwater resources and financing groundwater development schemes especially in the critical and semi-critical areas is emphasised.

I. INTRODUCTION

Water resources are a national asset of major importance for the country's economy. This vital resource is becoming a scarce commodity and as such requires to be planned, developed and managed with utmost care. Groundwater in particular plays a critical role in meeting the growing needs of our nation for drinking, domestic, industrial and irrigation purposes.

The current level of groundwater development is about 30% of the utilisable groundwater resource for irrigation. However the development is not uniform all over the country and in a number of areas intensive groundwater development has led to problems like declining water levels, shortage in supply and saline water encroachment. These problems are exacerbated during droughts during which water shortages are common across extensive areas. Urban areas are also facing major water shortages. In these areas rapid expansion and industrialisation is threatening the existing water supply systems which may not be able to meet the growing demands in the future. Due to the emergence of shortages in drought prone areas, urban centres and in areas where groundwater development has already reached a high stage, there is need for strict measures of conservation and to augment groundwater resources. In view of the varied hydrogeological conditions in the country, technologies for conservation and augmentation of groundwater resources which are suited to the local hydrogeological situation and economically viable have to be evolved through intensive studies and experimentation.

Shortages are not the only water management problem. In canal command areas waterlogging and salinity due to excessive seepage of water applied for irrigation are common. As a result, it is important to develop systems for conjunctive use of surface and ground water. This can combine the advantages of groundwater storage with surface water delivery systems and serve as both a remedial and corrective measure for efficient water management and use.

Existing provisions and legal measures to control the development of groundwater resources in the country are not adequate and there is an urgent need for enforcing comprehensive and effective legal control and regulation for the development of groundwater resources in the country.

II. GROUNDWATER DEVELOPMENT IN INDIA

The use of groundwater in India for irrigation has taken place from time immemorial. The history of open well construction can be traced back to the epic of vedas (3000 B.C. to 800 B.C.) wherein mention has been made concerning irrigation from wells. Localised use of groundwater through open wells continued during medieval periods particularly in areas where surface water supplies were not available. Toward the end of the nineteenth century, open wells formed an important source of irrigation and accounted for nearly 30 percent of the total irrigation in the country. The first large scale venture in the development of groundwater for irrigation was taken in 1934 when a project for construction of about 1500 public deep tubewells in the Ganga basin was initiated. Since the middle of the 1960s the importance of groundwater for irrigation has been increasingly realised. Recurrent droughts, the advent of high yielding varieties of wheat and rice (which require timely and carefully managed irrigation) and the introduction of an incentive oriented agricultural price policy by the Government, paved the way for extensive development of groundwater irrigation in the country.

Until the end of the second Five Year Plan (1960-61) the groundwater development programme was dependent largely on Government resources. Institutional investment through banks grew rapidly with the setting up of the Agricultural Refinance and Development Corporation (now National Bank for Agriculture and Rural Development, NABARD) in 1963. This was done with a view to i) supplement the resources of existing institutions which were charged with dispensing medium and long term loans for agricultural development (such as Land Development Banks, State Cooperative Banks and Commercial Banks) and ii) reorienting the operational policies of these institutions in order to make them responsive to growth oriented lending. In addition to NABARD, the Rural Electrification Corporation is the backbone of the minor irrigation programme. It is particularly important for groundwater development as it provides the most economical and efficient means of lifting water.

India has a very large cropped area under irrigation. Of the total cultivable area, estimated at 186 Mha, the present cultivated area (as of March, 1990) is reported to be 143 Mha. This is also termed the net sown area. Taking into account the multiple cropping adopted in different seasons, the total gross cropped area is estimated at 175 Mha. The gross irrigated area (as of March, 1990) is about 75 Mha which represents about 42% of the gross cropped area. The gross area irrigated from groundwater sources is on the order of 35.6 Mha which is 44.5% of the total area that can ultimately be irrigated from groundwater and is 47.5% of the total cropped area under irrigation.

Groundwater development in India is essentially a people's programme, implemented primarily through individual and cooperative efforts from finances obtained as loans (recoverable with interest) from institutional sources or invested by farmers from their own sources. Public sector outlay in the case of groundwater schemes is limited only to such items as groundwater surveys, public tubewells, services provided and grants extended to the small farmers. Unlike major and medium irrigation and surface water minor irrigation projects which are more or less entirely dependent on public sector outlays, the programme of groundwater development imposes very little burden on the public exchequer.

With the policy of the government to encourage institutional finance for groundwater development and the extension of electrification to rural areas, more and more farmers are constructing wells and tubewells. The number of groundwater abstraction structures has increased dramatically over the period 1951-90. Over this period, the number of dug wells has increased from 3.86 million to 9.49 million, shallow tubewells from 3000 to 4.75 million and public tubewells from 2400 to 63600. Similarly, the number of electric pumpsets has increased from 21000 to 8.23 million and diesel pump sets from 66000 to about 4.35 million.

III. GROUNDWATER RESOURCE POTENTIAL

India has diverse hydrogeological setting. Variations in the nature and composition of the rock types, the geological structures, geomorphological features and hydrometeorological conditions have correspondingly given rise to widely varying groundwater situations in different parts of the country.

Since groundwater is a dynamic and replenishable resource, the availability for different use purposes has to be estimated primarily based on the component of annual recharge which can be developed. The annual groundwater recharge of a country largely depends on hydrogeological and climatic conditions, particularly the level of precipitation.

Initially groundwater resource evaluation was carried out on a sectoral or regional basis for project purposes or to avail institutional finance. In 1972 guidelines for an approximate evaluation of groundwater potential were circulated by the Ministry of Agriculture (Government of India) to all state governments and related financial institutions. These norms were used for computation of groundwater resource availability on a blockwise basis all over the country. The methodology for groundwater resource evaluation was utilised to direct institutional finance for different groundwater development schemes.

In 1979, a high level technical committee known as the "Groundwater Overexploitation Committee", after detailed discussions and deliberations with the state groundwater organisations, recommended revised norms for evaluation of groundwater resources. Subsequently, the "Groundwater Estimation Committee" (1984) after making a review of the various aspects related to estimation of groundwater resources and the status of available data recommended a detailed methodology for the evaluation of groundwater resources in the country.

Based on available hydrometeorological and hydrogeological data, results of experimental studies carried out in special groundwater projects and data of various surface irrigation projects, and adopting the norms recommended by the Groundwater Estimation Committee, the utilisable groundwater resources of the country has been assessed as 45.34 million hectare metres per year. Out of this 6.83 m. Mha m are set apart for drinking, industrial and other committed uses and the utilisable groundwater resources for irrigation are taken as 38.51 Mha m.

IV. EMERGING PROBLEMS, OPTIONS AND STRATEGIES IN THE DEVELOPMENT AND MANAGEMENT OF GROUNDWATER

i) Overexploitation of Groundwater

As mentioned earlier the utilisable groundwater resources of the country have been assessed as 45.34 million hectare metres per year, and the utilisable groundwater resources for irrigation is 38.51 Mha m, out of which currently 11.58 Mha m are being utilised. This leaves a balance of 26.93 Mha m of groundwater resources still available for exploitation for irrigation.

From the national perspective, considerable scope for groundwater development still remains. However, at the micro-level there are pockets where intensive development has led to rather critical situations. Problems such as progressive lowering of groundwater levels and consequent decline in the yield and productivity of wells, increasing cost of lifting water, drying up of springs and shallow dug wells, reduction in the free flow, shortage in water supply, intrusion of seawater along the coast and even local subsidence are becoming evident at some places.

In the coastal region of Saurashtra, Gujarat, increasing groundwater development has resulted in saline water ingression and deterioration of groundwater quality. This has been compounded by percolation of tidal waters. Excessive use of saline water in turn affected the soil structure and the soil salt balance causing damage to the soils, reduction in crop yields, etc. In Mehsana area, Gujarat, excessive groundwater exploitation has resulted in progressive decline in water levels in the shallow aquifers (phreatic and semi-confined) in the central and south central parts of the district. Similar problems exist in the Chandigarh area and Kurukshetra area of Haryana State, and in some pockets of Tamil Nadu, Andhra Pradesh, Maharashtra, Punjab and Rajasthan.

As of January 1992, there are 257 blocks (28 in Andhra Pradesh, 24 in Haryana, 9 in Karnataka, 3 in Madhya Pradesh, 69 in Punjab, 63 in Rajasthan, 43 in Tamil Nadu, 17 in Uttar Pradesh and 1 in West Bengal), 18 talukas (in Gujarat) and 34 watersheds (in Maharashtra) which are classified as dark or critical blocks/areas. In these areas, the projected net extraction five years following the time of resource evaluation will be in excess of 85% of the utilisable groundwater resource for irrigation. Similarly, 361 blocks, 14 talukas (Gujarat) and 57 watersheds (Maharashtra) have been classified as grey or semi-critical where the projected net extraction in year 5 is between 65 and 85% of the utilisable groundwater resource for irrigation. In the critical blocks further development is not warranted and in the blocks tending towards criticality further development must be done with caution.

In sum, although adequate groundwater is available in the country for further development, there are certain areas in each state having high demand for groundwater for irrigation but showing a declining trend in groundwater levels. Since increasing the irrigated area through groundwater development has been identified as a high priority by the government, this situation needs to be monitored. Therefore, there is a need to analyse in depth the problems that have emerged due to extensive groundwater development in the last few decades. Some of the issues that need indepth study and critical review include:

1) What area is appropriate for categorising development levels, e.g. dark (critical) and grey (semi-critical). In 1984, the Groundwater Estimation Committee recommended that in case of critical and semi-critical areas detailed micro-level studies should be carried out and that the blocks categorised as critical and semi-critical should be divided into small units, of at least 100 sq km areal extent. Is this type of approach adequate? The problem is if only a small part of the area is overdeveloped and other parts are underdeveloped can we restrict/stop the development throughout the entire area? If so what should be the optimum size of the unit area for categorising it as critical or semi-critical?. If we permit development on the basis of small unit area, what will be the overall position related to the availability of sufficient groundwater resources?

2) Is the current methodology adopted for estimation of groundwater resources especially in the hard-rock and the coastal areas appropriate or does it need any refinement or change?

3) Are the socio-economic issues involved in the development of groundwater properly evaluated and considered, and how effective are our measures to regulate and control overexploitation of groundwater, especially for irrigation?

These issues call for a thorough review of all the aspects involved in the development of groundwater resources and the financing of groundwater development schemes in the critical and semi-critical areas. Possible options and strategies for the development and management of groundwater resources have to be carefully evaluated so that feasible solutions that ensure safe and optimum development of this vital resource for the welfare of our country and the well-being of its teeming millions can be identified.

B) Groundwater Development and Management in Hard-rock Areas

Groundwater development in hard-rock areas is beset with many uncertainties. The nature of rock type, degree and genesis of secondary openings and capacity to hold and transmit water under normal conditions are some of the problems which need to be evaluated with a fair degree of accuracy. Studies by the Central Ground Water Board have indicated that the rate of recession of groundwater levels in alluvial formation is slow compared to that in hard-rock areas.

In hard-rock areas, the rate of recession of the water level is quite fast for the first one and half months after the peak. However due to less demand for water during this period, the resource available may not therefore be fully utilised. This fact has been taken into consideration while recommending the methodology for estimation of utilisable recharge by the Groundwater Estimation Committee. As a matter of fact, in most of the hard-rock areas the water level in the aquifer comes near the surface immediately after the first few showers in the monsoon. Subsequent rains will only result in rejected recharge unless there is considerable gap in the heavy showers. If groundwater available in these hard-rock aquifers can be made use of during the monsoon period, especially during the gaps in rain spells, the potential of these aquifers can be increased. Further, after the rainy season, by methods of artificial recharge and techniques of water conservation, the groundwater resources of these hard-rock areas can be augmented. However, since the thickness of the weathered and fracture zone in hard-rock areas is limited, the available storage space will be a limiting factor for effective recharge of the hard-rock aquifers.

Another factor that limits large scale recharge of groundwater in the hard-rock aquifers is the heterogeneous nature of these aquifers and noncontinuity of the aquifer zones. As a result, artificial recharge/techniques which are localised in nature such as percolation tanks, subsurface dykes, check dams and nala bunds (small dams in gullies) will be more effective than injection wells in case of these hard-rock areas.

In the hard-rock areas, which cover the entire Deccan Plateau and many other parts of the country, hydrogeological investigations and groundwater exploration have indicated that some of the deep zones are good aquifers. Their aerial extent and potential are, however, limited. Analysis of pumping tests on wells tapping such zones showed that the specific capacity of these wells declines rapidly after a certain period of pumping, indicating limited storage conditions. The National Water Policy gives first priority for providing reliable and safe drinking water to rural and urban populations. Drinking water needs are small compared to irrigation needs. As such, development of such deep aquifer zones with limited potential in hard rock areas for irrigation may has to be discouraged and these aquifer zones must be developed to meet drinking water needs.

The deep fracture zones in these hard-rock areas are recharged through the top weathered and fracture zones and any major exploitation programme of these zones will necessarily be at the expense of the shallow aquifers. It is not out of context here to appreciate the damage caused to the weathered zone in the drought prone areas of Anantpur district of Andhra Pradesh as a result of intensification of groundwater development during the last decade. The dug portions of the existing wells in this area now remain mostly dry and serve to house the pumps which are directly connected to in-well boreholes. The net yields of most of the wells have suffered appreciable reduction. The strategy should therefore be oriented toward augmenting recharge for these aquifers through appropriate artificial recharge measures and toward conserving groundwater through application of effective irrigation management techniques such as drip and sprinkler irrigation systems. Drip irrigation is becoming increasingly popular and cost effective for tree plantations in these hard-rock areas with low groundwater potential.

C) Groundwater Development and Management in Coastal Areas

Coastal regions have always drawn the attention of mankind and posed problems for development from the standpoint of water supply. These regions have their own set of problems. The major rivers in our country discharge into the ocean. The large amounts of water discharged by them could serve as a major source of freshwater supplies if it could be captured before mixing with saline ocean waters.

In addition to river discharges, extensive surveys and exploration activities over the years have revealed the existence of large fresh groundwater resources in the coastal region of the country. These groundwater reservoirs, each within its specific hydrogeologic context, need to be well understood before development plans are evolved. Almost everywhere fresh water and saline water systems in the sub-surface are in direct hydrologic contact. The hydro-dynamic balance between them can easily be disrupted unless groundwater development proceeds cautiously.

Management of groundwater in the coastal environment therefore depends heavily on developing as precise as possible an understanding of the local geology. In fact, the more precise our understanding of the hydrogeologic environment is, the better we can identify appropriate operating mechanisms for controlled groundwater withdrawal without upsetting the hydrochemical and hydro-dynamic balance. In normal situations, if the salinity constraint had not been there, being in the discharge area, these aquifers would have permitted even unrestrained withdrawal within the permissible economic limits. Every effort has to be made to optimally develop the groundwater resources in coastal regions to meet the ever increasing demands for freshwater. At the same time, due regard to the freshwater/saltwater balance is required to avoid damage to the aquifer.

The National Water Policy clearly states that "overexploitation of groundwater should be avoided near the coast to prevent ingress of seawater into sweet water aquifers". At present, no legal control or regulatory measures are present in the country by which overexploitation of groundwater in coastal areas could be prevented. Realising this, in the First National Water Convention held at New Delhi in November 1987 it was recommended that legislation establishing controls over groundwater extraction in coastal regions should not be postponed and the concerned states must take the initiative for adoption and implementation of the legislative measures.

D) Waterlogging and conjunctive use of surface water and groundwater

With the advent of intensive irrigation through surface irrigation projects in many canal command areas the water table is progressively rising. This has already created waterlogging and salinity problems in several parts of the country. These problems are due to excessive seepage from surface irrigation and poor subsurface drainage. They make soils unproductive and restrict the growth of plants, resulting in decline in crop yields. When the water table rises to between 0 and 1.5 m below the surface it begins to affect crop yield (0 for rice, 1.5 m for other crops). In general, areas with water tables within 2 m below ground level can be considered prone to waterlogging and those with water table between 2 and 3 m below ground level may be viewed as critical areas wherein any additional input of water without protective measures can turn them into waterlogged areas.

The National Commission of Agriculture (1976) made an estimate of waterlogged areas based on the work carried out by various agencies. About 60 lakh hectares of area in the country was considered as waterlogged. Of this 34 lakh hectares is because of surface flooding, mostly in the states of West Bengal, Orissa, Andhra Pradesh, Uttar Pradesh, Gujarat, Tamil Nadu and Kerala. In the remaining 26 lakh ha, the waterlogging is due to rise in groundwater levels.

Conjunctive use of surface and groundwater can serve as a remedial and corrective measure to address waterlogging problems. It combines the advantages of groundwater storage with the surface water system. In India, conjunctive and integrated use is taken to imply the coordinated and harmonious development of ground and surface water sources with the sole purpose of maximising agricultural production. For optimum production the crop must be provided requisite quantity of water at various critical stages of growth. For various crops with different base and critical periods, total requirements are often difficult to meet from either surface or ground water individually. Conjunctive use can solve this problem. In addition, conjunctive use of surface and ground waters provides a range of possibilities for water supply including: (a) increasing the availability of adequate water supplies by supplementing surface resources with groundwater at any point of time, (b) enabling advance irrigation in a season prior to availability of surface water and (c) enabling late waterings when surface water is not available.

Joint operation of the surface water and groundwater systems would require systematic management on the basin level. This, in turn, requires an understanding of the groundwater system and its response to the stresses imposed upon it. It also requires an understanding of the economics of water resources allocation. The totality of the problem with reference to agricultural water use emerges when the allocation of water between surface and underground sources to various crops in a region for an optimal cropping pattern is linked with an optimal irrigation schedule both in terms of timing and quantity of irrigation water application.

In surface irrigation projects, inadequate attention is generally given to groundwater. Surface projects generally involve extensive field surveys and investigations which are used to identify the culturable command to ensure that it is possible to deliver adequate water supplies. What is equally important is to fully understand the nature and extent of the underlying groundwater reservoir. This must be developed to its optimal long term potential and increasingly exploited to prevent the occurrence of waterlogging and land salinisation/ alkalinisation.

The planning process of such projects must, therefore, include field information facilitating the interpretation of subsurface hydrology including the dimensions of the groundwater reservoir, disposition of the aquifer system and yield potentials. This is necessary to decide upon the appropriate groundwater structures for pumping groundwater to the predetermined quantum and to regulate withdrawals so as to prevent waterlogging conditions. The information would also enable fixation of effective culturable command area (C.C.A.), establish appropriate ground and surface water mixes and lead to corrective steps in groundwater management to combat drought and ensure uninterrupted water supply for agriculture, domestic and related uses. All projects for conjunctive use of surface water and groundwater should be developed, operated and maintained from project funds for optimal water resource development.

Integrated and conjunctive use of surface and ground waters, has not so far been given the extent of attention and consideration it deserves. There is a dire need for developing it on more scientific lines in order to derive its full benefits. As the tools of modern technology have become more sophisticated by the development of high speed digital computers and related mathematical techniques, it is now possible to study the problems in a broader perspective and evolve optimal solutions that take into consideration all technical components of the problems along with economic, social and environmental aspects.

V. NEED FOR GROUNDWATER MONITORING AND LEGISLATION

The growing complexity of modern society puts increasing stress on groundwater. In a situation characterised by phenomenal growth of groundwater use, it is of utmost importance that groundwater regime in different hydrogeological situations in the country is monitored regularly with respect to quantity and quality. To keep a watch on the groundwater situation in different part of the country and to study the response of groundwater levels to increase or decrease in the amounts of inputs from various sources, the Central Ground Water Board has set up a national network of observation wells and is monitoring water level and water quality in them. As of March 1993, 15972 observation wells had been established. Three thousand more observation wells are planned during the VIII Plan period. It is necessary to critically review the adequacy or need for additional stations in the light of the complex hydrogeological situation in the country. More monitoring stations are required in order to get a reliable picture of the groundwater situation. There is also a need for the development of a suitable data base system. It is necessary to use automated instruments for groundwater level data collection and micro-processor based data system for recording and transmission of data. Software is also required to analyse these data and enable comprehensive system stimulation and forecasting studies.

Administrative measures are the only control being adopted at present in India for regulating groundwater development. The control that exists at present is through indirect measures being adopted by institutional financing agencies, who by and large insist for technical clearance of proposed development activities from authorised Groundwater

Departments of the respective states. These departments in turn look into various aspects of groundwater availability and scope for further development in the area under reference.

Legislative competence and responsibility for water lies at the state level except in the matter of interstate rivers. This is true for groundwater as well as surface waters. Relatively few legislation pertaining to groundwater has been passed in the different states. The Government of Uttar Pradesh enacted the U.P. State Tubewells Act in 1936. At a much later date Punjab also enacted the Punjab State Tubewells Act 1954. These acts provide for construction and maintenance of state tubewells and supply of water from them. Due to intensive groundwater development and related problems, the State of Gujarat and Tamil Nadu seriously considered the necessity of introducing legislations to regulate groundwater. In Gujarat State, after protracted deliberations, it was possible to have a law on groundwater (the Bombay Irrigation (Gujarat Amendment) Act 1976) through an act of the president. The responsibility for bringing into force and implementing this act devolved on subsequent popular governments.

A working group consisting of representatives of Central Government (including law ministry) and various State Governments was constituted in the 1960s by the Government of India to draft a model bill for the control and regulation of groundwater. The Draft Model Bill 1970 was circulated to different States for adoption and enactment through the State Assemblies. The Model Bill could not make much headway and the States were unable to introduce legislations on groundwater, as advised by the Government of India.

The Model Irrigation Bill 1976 prepared by the Ministry of Irrigation, Govt. of India, in collaboration with the Indian Law Institute, provides for declaration of certain areas for irrigation works and prohibits construction of wells except with previous permission. The use of State Government wells exclusively for domestic purposes is however exempted. The control over groundwater contemplated by the bill is limited. It is limited in objective and provides for measures in the interest of proper irrigation from any irrigation work. The regulation of groundwater does not extend beyond this purpose.

A revised Model Bill to regulate and control the development of groundwater (1992) has been prepared and circulated to all concerned. The revised Model Bill is basically the same as that of 1970 draft bill except that: (i) marginal and small farmers need not have permission to construct wells -- they only have to inform the authorities if they wish to do so, and (ii) wells constructed for the purpose of drinking also come under the purview of this regulation.

It is evident from the above that the existing provisions and legal measures proposed from time to time are inadequate and do not cover all the aspects of groundwater development and its control. As such there is an urgent need to evolve a procedure for enforcing comprehensive and effective legal control and regulation for the development of groundwater resources of the country.

SUMMARY AND CONCLUSIONS

India is a vast country with diversified hydrogeological setting. Variations in the nature and composition of the rock types and geological structures and hydrometeorological conditions have correspondingly given rise to widely varying groundwater situations in different parts of the country.

The utilisable groundwater resource in the country has been assessed as 45.34 million ha m per year and the current level of groundwater development is about 30% of the utilisable groundwater resource for irrigation. However the development is not uniform all over the country. Overexploitation of groundwater in certain areas has resulted in progressive lowering of the water levels and consequent decline in the yield and productivity of wells, drying up of springs and shallow dugwells and intrusion of springs along the coast. Therefore there is need to analyse in depth the problems that have emerged due to the extensive development of groundwater in the last few decades in certain areas.

Groundwater development in case of hard-rock areas is beset with many uncertainties - the nature of rock type, capacity to hold and transmit water, etc. The heterogeneous nature of these aquifers, noncontinuity of aquifer zones, and limited thickness of the weathered and fracture zone, limit the scope for large scale recharge of groundwater in these areas. Artificial recharge techniques such as percolation tanks, check dams, subsurface dykes, etc., which are localised in nature should be quite effective in augmenting the groundwater resources in these hard-rock areas. Use of drip and sprinkler irrigation systems will help in the effective use and conservation of groundwater in these low potential areas.

In case of development and management of groundwater in coastal environments, there is a need to precisely understand the hydrogeologic environment, in order to evolve an operating mechanism of controlled groundwater withdrawal without upsetting the hydrochemical and hydrodynamic balance. Every effort should be made to optimally develop the groundwater resources in coastal regions to meet the ever increasing demands for freshwater with due regard to the prevalent freshwater/saltwater interface in the areas.

Conjunctive use of surface and ground water combines the advantages of groundwater storage with surface water system and serves as both a remedial and corrective measure for efficient water management and use. A properly planned conjunctive use of surface and groundwater will also help to prevent the development of a situation leading to waterlogging in the canal command areas. This aspect should be included in the project, right from the planning stage and should be preferably implemented from the project funds.

There is a need for a thorough review of all aspects involved in the development of groundwater resources and financing groundwater development schemes especially in the critical and semi-critical areas. The possible options and strategies for the development and management of groundwater resources should be critically examined to arrive at technically feasible and economically and socially viable solutions to ensure safe and optimum development of this vital resource.

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GROUNDWATER OVEREXPLOITATION IN THE LOW RAINFALL HARD-ROCK AREAS OF KARNATAKA STATE

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Abstract

In Karnataka state, as in many other parts of the country, well irrigation has come into prominence since the 1960s. Since then rapid increase of wells and pumpsets has taken place. This resulted in sharp decline in water levels, which is more evident in the low rainfall, hard-rock areas of the State, particularly in the four southeastern districts of Bangalore, Chitradurga, Kolar and Tumkur. Farmers tackled the problem of declining water levels by constructing bore wells, which actually hastened the decline of water levels because these structures, by virtue of their depth, are capable of withdrawing more water than conventional dug wells. As a consequence, many dug wells became dry and the investment in them and in pumpsets for them was lost. Large numbers of farmers who had assured irrigation from dug wells until a few years back are now deprived of irrigation because they do not have the financial resources to attempt boring after the dug well became dry or because the bore well they attempted did not prove successful. Many such farmers have now switched over to dryland farming. The poorer among them are supplementing their meager farm income through agriculture labour.

A detailed study of two small watersheds in Malur taluka of Kolar district and Davanagere taluka of Chitradurga district was conducted in February 1993 to understand the implications of water level decline in the hard-rock areas of Karnataka state.

INTRODUCTION

Karnataka, the sixth largest state in India, occupies an area of 19 million hectares (Mha) and is divided into 20 districts. It is classified physiographically into the Coastal Region, the Malnad Region (hill areas lying to the east of western ghats), the Northern Plateau and the Southern Plateau (Figure 1).

Soils

Alluvial soils occur in the coastal region and the river valleys, whereas the Northern Plains are occupied by black, clayey soils. Light textured, red soils occur extensively in the Southern Plateau. Lateritic soils predominate in the Western Ghats.

Rainfall

Karnataka state receives rain in both southwest and northeast monsoons, the former contributing more. Normal annual rainfall of the State is 1138 mm which is highly erratic in both space and time, varying from less than 600 mm in the northern districts to 4000 mm in the coastal and Malnad districts. Rainfall in the vast Southern Plateau varies from 600 to 900 mm (Figure 2).

Hydrogeology

Nearly 98% of Karnataka state is occupied by hard rocks which include granites, metasediments and Deccan traps. These rocks lack primary porosity. Storage and transmission of groundwater in these rocks take place through secondary porosity, caused by weathering and fracturing (Raju 1985). Granites are the predominant rock type occurring in Bangalore, Bellary, Chickmagalur, Chitradurga, Gulbarga, Hassan, Kodagu, Kolar, Mandya and Mysore districts. Groundwater in granites is developed mostly through bore wells except in the shallow water level areas of Malnad and South Kanara districts where the traditional dug wells continue. Bore well depth in granites varies from area to area, ranging from 40 to 100 metres depending upon water levels and the occurrence of fractures. Metasediments occur in Dharwad and parts of Raichur, Chickmagalur, Shimoga, Belgaum, Bijapur, Tumkur, Chitradurga, Bellary and North Kanara districts. Bore wells in these rocks are around 50 metres in depth. Groundwater development in Deccan Traps occurring in Bidar and parts of Gulbarga, Belgaum and Bijapur districts is taking place through deep bore wells ranging in depth from 80 to 90 metres. Alluvium and laterite in the districts of South and North Kanara, Bidar and Gulbarga are developed by shallow open wells.

GROUNDWATER DEVELOPMENT

Agriculture development in drought prone areas is fraught with multiple risks, emanating essentially from inadequate and erratic rainfall. Farmers in such areas, through centuries long trial and error, have established farming systems with technologies suited to their needs (Dillon 1986). The irrigation technology developed traditionally by farmers in the hard-rock areas of Deccan Peninsula was dominated by tanks till the middle of the present century. The three southern states of Andhra Pradesh, Karnataka and Tamil Nadu have more than one lakh irrigation tanks, with Karnataka alone accounting for 38,000.

Since Independence, with the shift in ownership of tanks to the State Government, their management has suffered. Encroachment and siltation of tank beds have drastically reduced the irrigation capacity of these structures. Most of the tanks are in need of desilting, strengthening of bunds and modernisation of conveyance and distribution channels. Beneficiaries are disorganised and have no involvement in managing the tanks. The State Government is unable to raise the resources needed to rehabilitate them. As a result, a large number of tanks which were recharging groundwater in addition to providing irrigation are

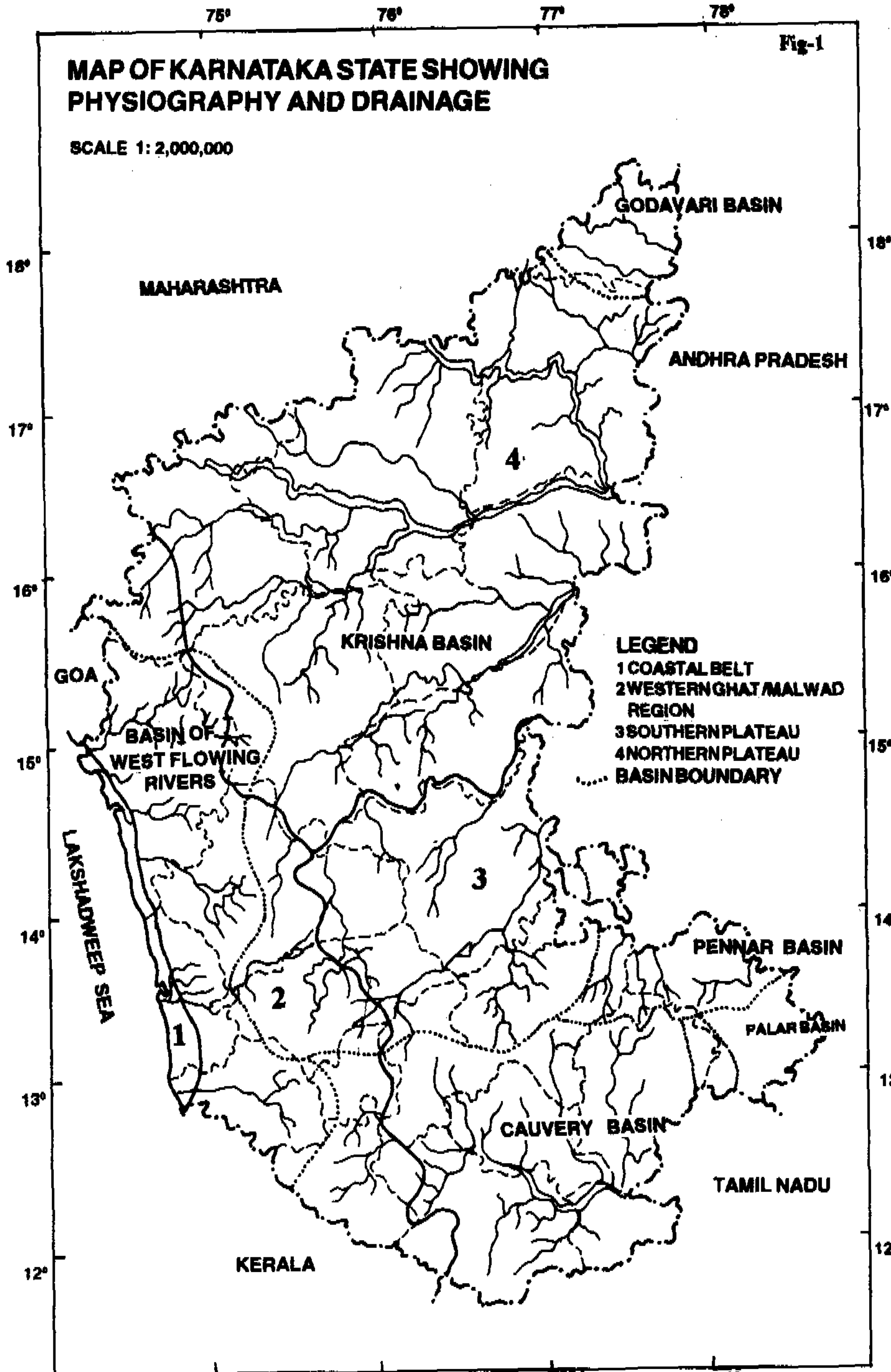
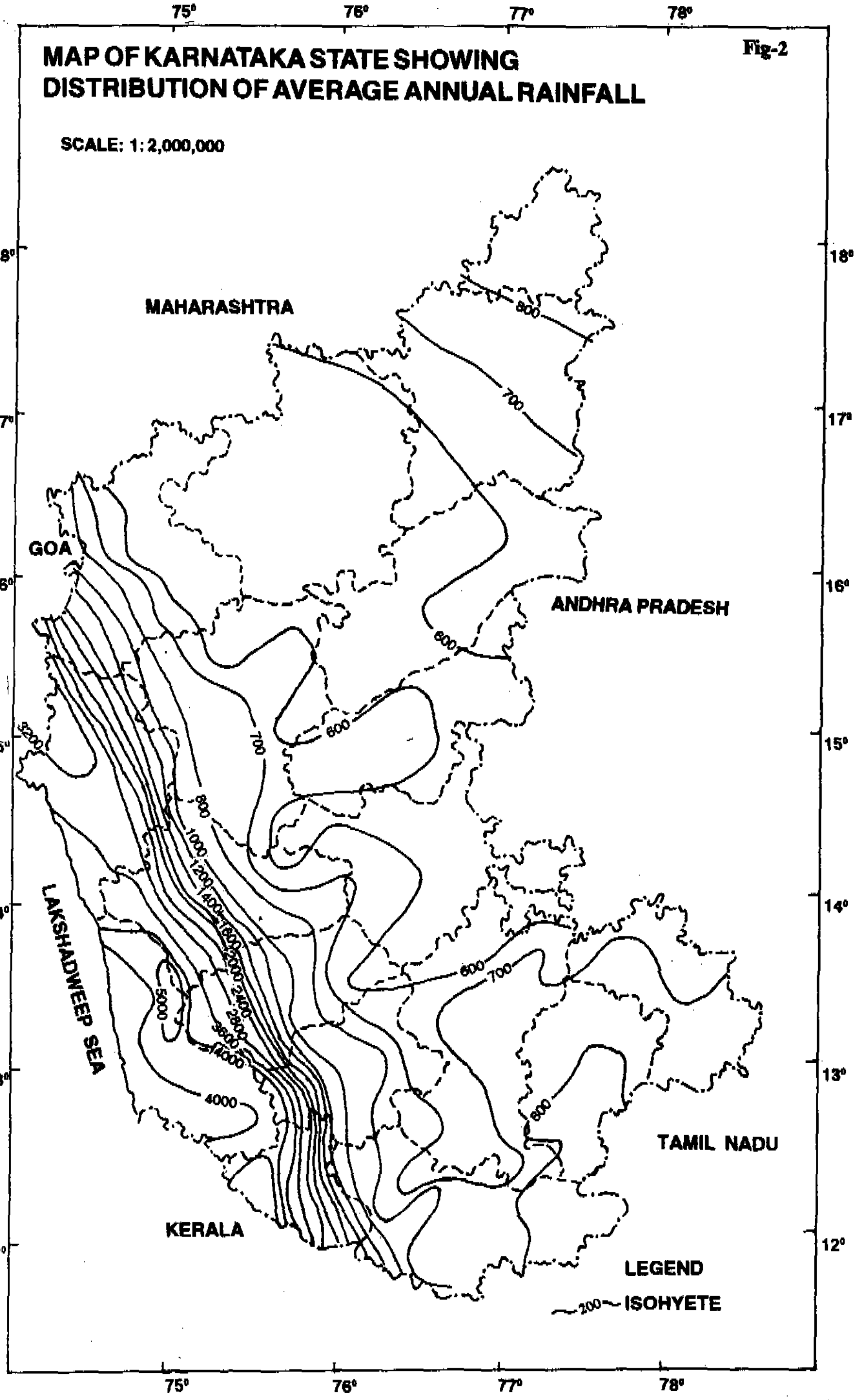


Fig-1
MAP OF KARNATAKA STATE SHOWING
PHYSIOGRAPHY AND DRAINAGE
SCALE 1: 2,000,000
75°
76°
77°
78°
18°
17°
16°
15°
14°
13°
12°
GODAVARI BASIN
MAHARASHTRA
ANDHRA PRADESH
4
KRISHNA BASIN
GOA
LEGEND
1 COASTAL BELT
2 WESTERN GHAT /MALWAD
REGION
3 SOUTHERN PLATEAU
4 NORTHERN PLATEAU
BASIN BOUNDARY
BASIN OF
WEST FLOWING
RIVERS
3
LAKSHADWEEP SEA
PENNAR BASIN
2
1
PALAR BASIN
CAUVERY BASIN
TAMIL NADU
KERALA


MAP OF KARNATAKA STATE SHOWING
DISTRIBUTION OF AVERAGE ANNUAL RAINFALL
Fig-2
SCALE: 1: 2,000,000
75°
76°
77°
78°
18°
17°
16°
15°
14°
13°
12°
MAHARASHTRA
GOA
ANDHRA PRADESH
LAKSHADWEEP SEA
TAMIL NADU
KERALA
800
700
600
1000
1200
1400
1600
2000
2400
2800
3600
4000
5000
3200
LEGEND
200 ISOHYETE

now in disrepair. In a short period of 25 years since 1950-51, the proportion of tank irrigated area to net irrigated area had declined in the country from 17.2 to 11.6% (Von Oppen et al. 1982).

Karnataka is drained mainly by Cauvery and Krishna River systems (Figure 1). These two rivers have flow during the major part of the year and, along with their main tributaries, support gravity and lift irrigation in the districts of Belgaum, Bellary, Bijapur, Gulbarga, Hassan, Mandya and Raichur. It is estimated that the state has an ultimate irrigation potential of 3.5 million hectares (Mha) through major and medium irrigation, out of which only 0.85 Mha (24%) was developed by the end of 1991-92. Though major irrigation has vast potential and is also receiving the attention of the Government, the high initial cost, cost and time overruns, inter-state disputes and environmental and ecological problems are inhibiting its expansion.

With serious limitations in rehabilitating tank irrigation and expanding canal irrigation, the attention had shifted to groundwater irrigation since the 1960s. Farmers were drawn to well irrigation because of the private ownership it offered. Planners were attracted to it because of its vast potential, quick implementation without gestation and relatively lower cost of construction.Various Government sponsored programmes subsidising well construction, easy availability of institutional credit and rapid rural electrification have speeded the development of well irrigation in many parts of the country during the last three decades (Rao 1991).

In 1960-61 Karnataka state had only 1.35 lakh dug wells, most of them operated by bullocks and mhotes. Most such wells had low discharges -- sufficient to irrigate about 0.4 ha of lightly irrigated crops. There existed a balance between the low potential of hard rocks and the low output of the dug wells. Under those conditions groundwater levels were high and construction of dug wells was cost effective because their depth rarely exceeded 10 metres. Well failure was uncommon because the dug wells tapped mostly the weathered zone which is a reliable aquifer, as compared to the underlying fractured zone.

Since the 1960s, centrifugal pumpsets have become exceedingly popular because of their low cost, high efficiency and easy maintenance. In a span of 20 years since 1960-61, the number of pumpsets increased from 0.27 to 3.38 lakhs. By March 1993, electric pumpsets alone increased to 8.69 lakhs in Karnataka (Table 1).

Table 1. Growth of Pumpsets in the Southern States

Sr.	State	Numberof Pumpsets (000's)			Annual growth			
		60-61	68-69	73-74	rate(%)	77-78	79-80	84-85
1.	Andhra Pradesh	52	161	376	59	468	547	820
2.	Karnataka	27	123	229	70	307	338	499
3.	Tamil Nadu	155	477	764	26	913	1000	1177

Source: Report of the Working Group on Minor Irrigation, GOI 1989

While well-owners were switching over to pump irrigation, new wells were coming up simultaneously in increasing numbers. Karnataka witnessed a three-fold increase in wells, from 1.35 lakhs in 1960-61 to 5.10 lakhs in 1984-85, recording an annual growth rate of 11% as compared to 2.9 and 4.5% in the neighbouring states of Tamil Nadu and Andhra Pradesh respectively (Table 2).

Table 2. Growth in Well Numbers

Sr. No.	State	Number of Privately Owned Wells (000's)					
		60-61	68-69	73-74	79-80	84-85	Annual growth (%)
1.	Andhra Pradesh	500	676	775	919	1,067	4.5
2.	Karnataka	135	280	325	415	508	11.0
3.	Tamil Nadu	875	1,140	1,410	1,472	1,522	2.9
4.	All India	4,562	6,460	7,838	9,918	12,101	6.6

Source : Report of the Working Group on Minor Irrigation, GOI 1989

Groundwater draft in Karnataka was hardly 64,800 hectare metres (ha m) in 1960-66. It increased 8.2 times by 1984-85 (unit draft per dug well, operated by bullock power is taken as 0.3 ha m and by pumpset as 1.2 ha m as per the norms of the State Ground Water Department). Such a steep increase disturbed the balance between groundwater recharge and withdrawals and resulted in decline in water levels in many areas -- particularly those characterised by a high density of wells and pumpsets such as in the southeastern districts (Table 3).

Table 3. Share of Southeastern Districts in Wells and Pumpsets (1986-87)

Sr.	Groundwater Structure	Number of Units		Share of Southeastern Districts (%)
		Southeastern Districts	Karnataka State	
1.	Dug wells	1,38,125	4,05,860	34
2.	Bore wells	25,181	48,060	52
3.	Electric Pumpsets*	1,96,111	5,37,888	37
4.	Geographical area Mha	2.71	19.18	14
5.	Groundwater draft Mha m**	0.21	0.55	36

*For 1985-86

**As of August 1992

Source: Karnataka at a Glance, 1989-90

As a result of sharp and secular decline of water levels, the saturated thickness is constricted resulting in reduced aquifer transmissibility. This implies that in the future, even at the same rate of pumping, the rate of water level decline will be much faster. Under these conditions, water levels could stabilise only if pumping is reduced drastically.

The groundwater assessment of Karnataka made by the State Groundwater Department in December 1990 shows that hardly 25% of the utilisable recharge is developed in the state, leaving scope for constructing 14 lakh additional wells. Even in the southeastern districts scope for 1.80 lakh additional wells is identified. However, with sharp decline in water levels, field realities in most of the areas are different and the groundwater balance estimated by the State Groundwater Department appears to be grossly overestimated. It is mainly because the Groundwater Department considered the fluctuations in water table as recorded in dug wells for estimation. This practice is adopted even in the southeastern districts where the irrigation structures are invariably bore wells. Water levels in the dug wells do not represent the true picture as these structures are mostly located in favourable hydrogeological conditions. The groundwater estimates will be more realistic if the fluctuation recorded in observation bore wells is considered along with the specific yield corresponding to that zone of fluctuation. Besides, while estimating the feasible number of wells, areas not suitable for development due to unfavourable hydrogeological conditions, such as the absence of fractures, very deep water levels approaching the bed rock etc., are not accounted. Arriving at the number of wells purely on the basis of groundwater balance estimated by volumetric methods without the above correction is bound to result in overestimation of potential.

RECOURSE TO BORING TECHNOLOGY

With the decline in water levels, the depth of dug wells could not be restricted to the weathered zone. Wells had to penetrate the underlying fractured zone. This was done through blasting, which is a slow and expensive process. Farmers, therefore, preferred boring from the bottom of dug wells instead of the conventional excavation. Such "dug-cum-bore" wells initially allowed the use of centrifugal pumpsets which had been installed already on dug wells. However, such wells were of limited use as water levels receded beyond the suction limit of the centrifugal pumpsets. Eventually farmers had to switch over to deeper surface bore wells, for whose operation costly submersible pumpsets had to be installed. This commenced in the early 1980s, marking an important phase of groundwater development in the state (Rao 1992).

Bore wells certainly have several advantages over the conventional dug wells. These structures could be constructed quickly (bore well of 50 metre depth is drilled in about 12 hours). By virtue of greater depth the bore wells can be pumped continuously. Also, the need for frequent deepening as in the case of dug wells is obviated. These factors encouraged Karnataka farmers to construct more and more bore wells. Ironically, bore wells, constructed as a solution to declining water levels, actually caused further decline because these structures are capable of pumping more water. Moreover, with the onset of bore wells, farmers could not revert to dug wells because the declining water levels made dug wells vulnerable to failure. In hard rocks, an area could be developed exclusively by dug wells or by exclusively bore wells because dug well irrigation is not stable if carried out along with bore wells.

Since the 1980s when bore wells entered the scene, the conditions in the State have been highly favourable to their proliferation. The Government of Karnataka encouraged bore well construction by extending liberal subsidy schemes and also introduced insurance coverage against failures to protect the farmers financed under Government sponsored schemes (the insurance scheme has been withdrawn since May 1991 as the Insurance Agency found it uneconomical due to the high failure rate of bore wells).

EXPERIENCE FROM TWO MICRO WATERSHEDS

As a result of declining water levels a large number of dug wells have become dry in Karnataka, forcing the farmers to construct deep bore wells. The switch over from dug well to bore well irrigation has been traumatic. Farmers have had to face considerable uncertainty and financial strain because of large scale bore well failures. An attempt has been made to study the extent of groundwater overexploitation and its impact on design and type of wells, cropping pattern and socio-economic status of farmers. The findings of the study are presented in this paper under the broad categories of study area profile, sample size and data collection, consequences of bore well proliferation and problems faced by farmers in constructing bore wells. The power policy of the State Government and its impact on groundwater resource availability and distribution are also discussed. The issues emerging out of the study are summarised at the end of the paper.

Study Area Profile

Two small watersheds, viz. Chikkashivara watershed in Kolar district and Alur watershed in Chitradurga district, wherein groundwater development is high and the conditions are representative of those prevailing in the southeastern districts were purposely selected for detailed study.

Chikkashivara watershed and Alur watershed are characterised by undulating terrain and occupied by fertile red soils. Fractured granite is the aquifer in both the watersheds. Weathered zone is less than 10 metres in Alur watershed, whereas it is up to 25 metres in Chikkashivara watershed. Fractured zone is thick in Chikkashivara watershed, extending up to 60 metres below ground level whereas it is only 40 metres in Alur watershed. In both the watersheds wells are the main source of irrigation. In addition to wells, Chikkashivara watershed has 7 tanks irrigating 125 hectares, whereas in Alur watershed one tank irrigates 62 hectares. Tanks in both the watersheds are silted heavily and irrigation under them is not efficient. Land use pattern and other relevant features of the two watersheds are given in Table 4.

TABLE 4. Details of Land Use and Well Statistics of the Study Area

Sr. No.	Details	Chikkashivara Watershed	Alur State	Karnataka Watershed
1.	Geographical area	1,652 ha	1,996 ha	19.13 Mha
2.	Net sown area	1,156 ha	1,526 ha	10.50 Mha
3.	Irrigated area	298 ha	162 ha	2.09 Mha
4.	Sources of Irrigation:			
	(i) Canals	NIL	NIL	0.84 Mha
	(ii) Tanks	125 ha	62 ha	0.28 Mha
	(iii) Wells	173 ha	100 ha	0.67 Mha
	(iv) Others	-	-	0.30 Mha
5.	Per cent of net sown area to geographical area	70h	76	55
6.	Per cent of net irrigated area to net sown area	26h	11	20
7.	Number of DWs			
	(1982-83)	203	165	
	(1992-93)	0	0	
8.	Number of DWs per 100 ha of net sown area	18	11	4.5
9.	Number of DCBs/ BWs (1992-93)	134	116	48100
10.	Number of DCBs/BWs per 100 ha of net sown area (1992-93)	29	7.6	0.5
11.	Normal annual rainfall (mms)	580	730	1138

Source: Taluka Offices of Malur and Davanagere
Note: DW=P dug well, DCBh=P dug-cum-bore well; BW=P bore well;*P=P 1986-87

Sample Size and Data Collection

During the study, 177 farmers (111 in Chikkashivara watershed and 66 in Alur watershed) who owned dug wells were interviewed. The sample, which constituted nearly 50% of all dugwell owners, was made randomly. Data collected included the design and yield of dug wells, dug-cum-bore wells and bore wells, capacity of pumpsets, cropping pattern and crop yields. Information on the efforts made by farmers and the expenditure incurred by them after their dug wells became dry was also collected. Census information on wells, pumpsets, etc., was collected from the Revenue Department and the State Electricity Board.

CONSEQUENCES OF BORE WELL PROLIFERATION

As centrifugal pumpsets gained popularity well-owning farmers switched over to irrigation of intensive crops. This phenomenon is very conspicuous in the study areas of Chikkashivara watershed and Alur watershed. Because of proximity to Bangalore city which provides an excellent market, many farmers in Chikkashivara watershed started growing vegetables after installing pumpsets on dug wells. In 1982-83, more than 50% of the well irrigated area in Chikkashivara watershed was under vegetables. Similarly, in Alur watershed, 48% of the well irrigated area was under betelvine (a perennial crop consuming more water than heavily irrigated sugarcane) in 1982-83 (Table 5).

Table 5. Watershedwise Area under Intensive Crops

Sr. No.	Watershed	Well Irrigated Area (ha)		Well Irrigated Area under vegetables/betelvine (ha)	
		1982-83	1992-93	1982-83	1992-93
1.	Chikkashivara	80	44	41	24
2.	Alur	67	33	32	10

Large scale adoption of water intensive crops resulted of declines in well water levels. At that stage the prudent option should have been to cut down pumping and switch back to crops requiring less water, preferably widely spaced horticulture crops, and irrigate them through drip systems. But farmers in the southeastern districts, particularly in the study area did not relent even after the aquifer gave clear signals of stress but persisted with irrigation intensive crops by constructing dug-cum-bore wells and bore wells. This further aggravated the decline of water levels. The consequences of overexploitation are very severe in hard-rock areas and are clearly manifested in the study area as shown below.

Dry Dug Wells

About one decade back, Chikkashivara watershed had 203 dug wells, as compared to 165 in Alur watershed. At the time of field study in February 1993, all the above 368 dug wells had become dry. Loss of investment due to infructuous dug wells and centrifugal pumpsets in the two watersheds amounted to Rs. 111 lakhs at current prices. This loss is a direct consequence of declining water levels.

Water level data from the observation well at Malur, the Taluka Headquarters close to Chikkashivara watershed, is presented in the form of hydrograph in Figure 3. To facilitate correlation of water levels with precipitation, the monthly rainfall figures are also shown in the hydrograph.

Seasonal fluctuation of water levels in hard-rock areas is large owing to low aquifer specific yields. At times sharp decline of water levels due to consecutive drought years are recouped to original levels in good monsoon years. However, the steady water level decline recorded in Malur observation well is not a seasonal phenomenon but could be attributed to mining (overdevelopment) of groundwater. Even in 1983 and 1984, which were good rainfall years (674 and 717 mm respectively as compared to 580 mm of normal rainfall), water levels declined. The water level decline in 1988 was very sharp (the dug well in which measurements were being taken became dry and the observations were continued in a nearby well since December 1988). Water levels did not register any rise in 1991 when the rainfall was 52% more than the normal. Figure 3

It can be concluded from the above that even in good rainfall years significant rise in water levels might not result in the revival of the vast number of the abandoned dug wells if the current level of groundwater extraction continues.

Bore Well Failure

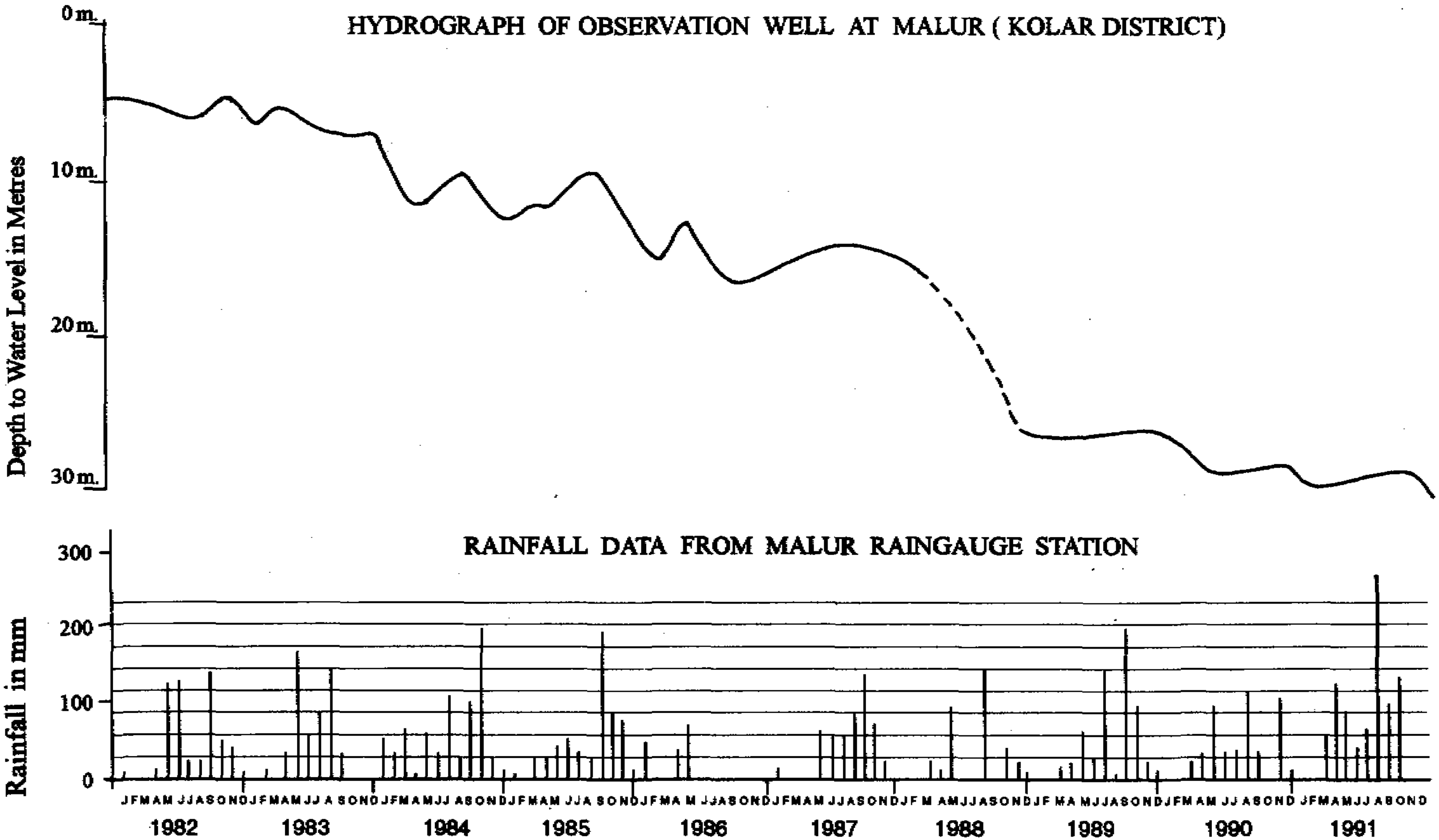
Farmers made vigorous attempts to sustain well irrigation after their dug wells became dry. In the study area, 80% of the farmers interviewed attempted to drill wells. Altogether, 378 bores (on average about 2 attempts per farmer) were completed of which 30 % were successful at the construction stage in Chikkashivara watershed as against the success rate of 23% in Alur watershed (Table 6).[18]

Table 6. Details of Boring Attempts Made in the Study Area

Sr. No.	Details	Chikkashivara Watershed	Alur Watershed
1.	Number of farmers interviewed	11	66
2.	Number of farmers who attempted boring	91	55
3.	Number of boring attempts since DW became dry		
	DCBs	89	79
	BWs	115	95
4.	Average depth of boring (m)		
	DCBs	30	24
	BWs	84	46
5.	Successful DCBs/BWs		
	at construction	63	40
	in February 1993	33	25
6.	Failure rate of boring attempts	84%	86%

[18]Under the insurance scheme of the Government of Karnataka, discharge below 1.25 litres per second was considered to be failure for a bore well. The same criterion is adopted in the present study for estimating the bore well failures.

Fig-3



Source: Department of Mines and Geology, Government of Karnataka

Diminishing Discharge from Bore Wells

Even in respect of successful dug-cum-bore wells and bore wells, the yield was not sustained because of fall in water levels. Many bore wells which yielded copiously at the time of construction recorded dwindling discharge over a period of time and were later abandoned or were operating far below the original discharge (Table 7). Out of 63 successful bore wells in Chikkashivara watershed, only 33 were yielding adequately (more than 1.25 litres per second) at the time of study. Similarly, in Alur watershed, only 25 out of 40 bores continue to give satisfactory yield. Out of the 378 boring attempts made by the farmers interviewed, 103 succeeded initially, hardly 58 were working satisfactorily in February 1993. This shows a staggering failure rate of 85% (Table 6). Number of bore wells in different discharge ranges at the time of their construction is compared with the position at the time of field study (Table 7).

Table 7. Number of Bore Wells in Different Discharge Ranges

Sr. No.	Watershed	Number of Bore Wells by Discharge					
		<1.25	lps	1.25 -2.50 lps		>2.50	lps
		Design	Present	Design	Present	Design	Present
1.	Chikkashivara	0	30	13	24	50	9
2.	Alur	0	15	14	21	26	4

As the data in Table 7 indicates, in Chikkashivara watershed as many as 50 bore wells out of the successful 63 initially successful ones had a promising design discharge of 2.5 litres per second or more at the time of construction. But at the time of field study, hardly 9 bore wells were operating at that discharge. While there was not a single bore well out of 63 with less than 1.25 litres per second discharge a few years back, as many as 34 bore wells were operating at that low discharge at the time of field study. Performance of bore wells in Alur watershed is equally grim.

For optimum pumpset efficiency it is essential to match the pump characteristics to the discharge and head conditions of wells. In view of the sharp decline of water levels and drastic reduction in discharge noticed in respect of almost all bore wells in the study area, mismatch of pump characteristics and site conditions has resulted in pumpset inefficiency. Moreover the decline in water levels means higher pumping heads and consequently higher power consumption (decline of one metre of water level results in each pumpset consuming additional power of 100 kwh per year). With more than 8 lakh electric pumpsets operating in Karnataka, most of them in areas characterised by decline in water levels ranging from 15 to 20 metres, additional power consumption as a consequence of groundwater overexploitation is enormous.

FARMERS' DIFFICULTIES

In view of the large failures encountered while constructing bore wells in hard rocks, proper siting of these structures assumes importance. Data collected in the survey indicates that 95% of the farmers did not attempt scientific site selection and preferred to engage local water diviners. Farmers informed the researchers that higher fees of geologists and the delay involved in conducting geophysical surveys dissuaded them from seeking their help. Systematic data collection, documentation and analysis are lacking. As a result, the fracture pattern is not adequately understood with the consequence that more and more bore wells continue to fail.

Many states, including Karnataka, have adopted the scheme of 'Compensation of Failed Wells' sponsored by the National Bank. Under this scheme, if a well fails the entire cost of the well (up to the unit cost approved by the National Bank) is compensated to the farmer by the Government. This scheme is limited to wells constructed through bank loans. However, despite persuasion by the National Bank, the Government of Karnataka is not enthusiastic about providing compensation coverage to bore wells, in view of the large failures encountered.

The high failure rate of bore wells and absence of compensation or insurance scheme have made banks wary about bore well loans. Banks insist that farmers invest first on drilling and approach them for loan disbursement only if the attempt is successful. In case of failure, farmer has to bear the entire cost of drilling -- about Rs.9000 for a bore hole of 60 metre depth. In the study area it was noticed that many farmers could not avail of bank loan even for successful attempts (bore well, complete in all respects, including the cost of drilling, casing pipe and submersible pumpset cost about Rs.40000) either because they had defaulted repayment of earlier loan or could not satisfy the well spacing norms. In Chikkashivara watershed, hardly 16 percent of the expenditure incurred by farmers since their dug wells became dry was raised through bank loans as compared to 26 percent in Alur watershed (Table 8).

Table 8. Details of Investment Made by Sample Farmers after the Dug Wells Became Dry (Rs. in lakhs)

Sr. No.	Watershed	Bank Loan	Own Resources	Total Incurred	Expenditure /Farmer	Expenditure Incurred/ha
1.	Chikkashivara	4.43	27.30	31.73	0.35	0.72
2.	Alur	6.26	23.81	30.07	0.55	0.61

It may be seen that each farmer, on the average, has invested Rs.35000 and Rs.55000 to sustain groundwater irrigation in Chikkashivara watershed and Alur watershed respectively since the dug wells became dry. This works out to Rs. 72000 and 61000 per irrigated hectare respectively, which is very high.

Returns on Bore Well Investments

After the dug wells became dry, the concern of the farmers was to restore well irrigation at any cost. Oblivious to the risk involved, farmers incurred heavy expenditure on drilling bore holes, most of them making repeated attempts because of failures. Even in respect of successful bore wells many farmers had to incur additional expenditure to deepen them because the bore wells which succeeded initially were dry after running for a few years.

A few examples are worth citing. K.T. Narayanappa of Doddakadathur village in Chikkashivara watershed drilled 11 bore holes in his 4 hectares of land and incurred an expenditure of more than Rs.1.00 lakh all of which has been lost because his attempts failed. S. Savappa of Alur watershed tried 5 dug-cum-bore wells initially which did not yield results. He followed up by drilling 8 surface bores since 1982-83, out of which 4 failed at the construction stage and 3 yielded satisfactorily for 1 to 2 years before failing. His last attempt, a bore well of 90 metres depth is now operating at 2 litres per second discharge. The farmer is, however, apprehensive that this bore well too may fail any day. Altogether, Savappa, who owns less than 2 hectares land has invested Rs. 0.90 lakhs in coping with receding water levels.

Farmers persisted with their attempts to construct bore wells despite repeated failures. They made one or two attempts in each favourable monsoon year when they had a little surplus funds. Most of the farmers, however, raised money from the village moneylenders at an annual interest rate of 36%. In a few extreme cases farmers sold part of their land to meet the cost of drilling. Only in respect of those few farmers whose bore wells are successful and have not registered any appreciable decrease in yields, the investment is viable. In all other cases income was much higher when the dug wells were operating successfully (see Appendix I). While attempting bore wells, farmers did so instinctively without considering the viability aspects. It is therefore necessary to educate the farmers to look for alternate investments instead of risking their scarce funds on bore wells. The Government and banks have a proactive role to play in providing suitable packages to farmers and weaning them away from self-defeating attempts to drill bore wells which, considering the high risk involved, amount to gambling.

Overdesign of Bore Wells

Productive fractures occur within 50 metres depth in the hard-rock areas of southeastern districts (CGWB 1987). However, the possibility of stray fractures occurring far below 50 metres cannot be ruled out. Attempts to tap such fractures are, however, risky and bound to result in a large number of failures.

In Chikkashivara watershed, productive fractures generally occur up to 60 metres, whereas in Alur watershed, they are restricted to 40 metres only as in this area the bedrock is at shallow depth. The average depth of bore holes drilled in Chikkashivara watershed is, however, 84 metres and several farmers have drilled beyond 100 metres. In Alur watershed the average bore well depth is 46 metres. Because of deep pumping water levels, bore well depth cannot be restricted to 60 and 40 metres in Chikkashivara and Alur watersheds respectively and farmers are forced to drill deeper, which has resulted in unproductive drilling and enormous wasteful expenditure in many cases.

POWER POLICY

Steep Increase in Energisation of Pumpsets

The Government of Karnataka stepped up energisation of agriculture pumpsets during the last one decade. The State had only 3.09 lakh electric pumpsets in 1980-81 which increased steeply to 6.75 lakhs by 1990-91. In the last three years alone, i.e. from 1990-91 to 1992-93, the State Electricity Board energised 1.82 lakh pumpsets (Table 9).

Table 9. Energisation of Agriculture Pumpsets in Karnataka State

Year	Number of Electric Pumpsets (000's)	
	Karnataka	Southeastern Districts
1979-80	290	126
1980-81	309	132
1981-82	332	140
1982-83	358	150
1983-84	396	164
1984-85	441	180
1985-86	490	196
1991-92	805	304
1992-93	869	368

In the study area also energisation of pumpsets picked up in the 1980s as compared to the previous two decades (Table 10).

Table 10. Number of Pumpsets Energised in the Study Area

Sr. No.	Watershed	Number of Pumpsets Energised		
		1960-70	1970-80	1980-90
1.	Chikkashivara	50	66	166
2.	Alur	60	50	97

It may be seen from the data in Tables 9 and 10 that the boom of energisation in the 1980s coincided with the advent and proliferation of bore wells. There is a strong link between pumpset energisation and bore well construction because bore wells cannot be operated efficiently without electric connections. In the neighbouring Tamil Nadu State where hydrogeological conditions are similar to Karnataka, farmers do not construct bore wells because it takes nearly ten years to receive electric connection and therefore they prefer to construct dug wells and operate them with diesel engines.

Discussion with the State Electricity Board officials revealed that in Karnataka, the targets for electric connections are determined depending upon the pending applications, i.e. on the existing demand. As a result, the southeastern districts, wherein demand for wells is high, though not supported by adequate groundwater balance receive higher proportion of electric connections for pumpsets, as compared to other districts in the state.

In Gujarat, installation of new electric connections for pumps in groundwater problem areas is contingent on approval by the State Groundwater Department (Moench 1992). It is essential that Karnataka State Electricity Board also takes into consideration the groundwater balance of each block before finalising the targets of pumpset energisation.

Free Power for Agriculture Pumpsets

The Government of Karnataka adopted the policy of supplying power at low and flat tariff since February 1981 (Rs. 50/BHP/year). As bore wells, unlike dug wells, can be operated continuously, the flat tariff was a strong incentive for prolonged pumping and cultivation of water intensive crops. In the absence of metreed power supply farmers use pumped water indifferently, least caring for conveyance, distribution and application efficiencies. The tendency of the farmers is typically "make hay while the sun shines". Even while irrigating water intensive crops, no efforts are being made to improve water use efficiency. Betelvine could be irrigated through drip system, saving more than 50 percent of the water presently used. Similarly, sprinklers could be used for irrigating the vegetables efficiently. Not even the small diametre PVC pipes, so commonly used in well commands for conveying and distributing water, are used in the study area. When the researchers inquired about such apathy, farmers informed that they were not keen to invest any further, not even for water conservation, as they were not sure as to how long the well would last and remain water bearing.

Appropriate pricing of electricity used in agriculture pumpsets is needed to discourage liberal withdrawals of groundwater, which has led to depletion of groundwater in water scarce regions (Dhawan 1991).

In the study area it was also observed that many farmers pump the bore wells throughout the night and store water in the dry dug wells. Water thus stored is pumped by centrifugal pumpsets in the morning when it is easier for the farmer to irrigate his fields. With the depth of dug wells around 15 metres, additional head involved is high. This additional pumping could be avoided if a small surface storage tank was constructed. Farmers avoid expenditure on surface tanks but in the process waste substantial power. In addition to inefficient use of pumped water, flat power tariff has also resulted in inefficiency of agriculture pumpsets throughout the country. Patel (1991) stated that pumpset efficiency measured in the field typically ranges from 13 to 27% as compared to 50% achieved in other parts of the world.

Though flat tariff is adopted in several other states, the damage due to it is telling in Karnataka because in this state introduction of flat tariff occurred along with proliferation of bore wells. The decision of the State Government to give free power to agricultural pumpsets up to 10 HP (it may be noted that almost all agriculture pumpsets are less than 10 HP) since June 1992 could be termed as the proverbial "last straw", because this step has deprived the Electricity Board of the little revenue it used to earn. The capital expenditure for energising a single pumpset is about Rs. 15000 and power costs about Rs.5000 per annum to generate (assuming that the average pumpset is 4 HP and operates for 1600 hours per annum).

The energy consumed by agricultural pumpsets was only 179 million units (MU in kwh) in the year 1970-71 -- about 6% of the total power consumed in the State. Since then power consumption by pumpsets has increased steadily and by 1991-92, it was 4,523 MU, constituting 36% of the total power consumed (Figure 4). Free supply of such large amounts of power has jeopardised the financial position of the State Electricity Board and prevented it from investing adequately in power generation to meet the ever increasing demand. The widening gap between supply and demand has affected the quality of power, resulting in extremely low and fluctuating voltages and consequently frequent burning of motors.

Unlike centrifugal pumpsets, submersible pumpsets can not be repaired by a village mechanic. They have to be hoisted from the bore well, taken to the nearby town for rewinding and installed after repair. The whole process is time consuming and upsets the irrigation schedule besides being expensive. In Doddakadathur village of Chikkashivara watershed, widely fluctuating voltage resulted recently in the burning of 23 motors in a single day. Each rewinding costs about Rs. 1200. Overall, the losses due to poor quality of power are enormous. On the average farmers in the study area spend about Rs. 950 every year for motor rewinding which is a direct consequence of poor voltage of power supplied. Supply of power with adequate and steady voltage will reduce drastically the need for such expenditure by farmers. Many farmers in the study area expressed willingness to pay up to Rs. 0.30 per kwh if power of adequate voltage is supplied at regular timings.

Marginal Farmers - The Worst Affected

Out of the 177 farmers interviewed who had dug well irrigation in the two watersheds a few years back, hardly 58 succeeded in switching over to successful bore well irrigation. Another 31 farmers, whose bore wells were successful initially, are operating them at very low discharge. The remaining 88 farmers who could not switch over to bore well irrigation are following dryland farming. This has seriously affected their economic and social well being. Poorer among them are supplementing the meager and uncertain income from dryland farming through agricultural labour.

Correlation analysis was attempted between the extent of land owned by farmers and the number of boring attempts made by them. A close association was observed with correlation coefficient of +0.60 in Chikkashivara watershed and + 0.58 in Alur watershed. This indicates that farmers who owned more land made more boring attempts.

A comparison was made between the average land owned by farmers who presently have successful bore well irrigation and those who never attempted boring after the dug well was dry (Table 11).

Table 11.

Sr. No. Watershed	Average Land (ha) Owned by Farmers Who Never Attempted Boring After the Dug Well was Dry	Average Land (ha) Owned by Farmers Who Own Successful Bore Well
1. Chikkashivarah	0.7	2.0
2. Alur	1.6	3.2

It may be seen from the above that generally farmers with less land have not attempted boring wells. Similarly, most of the farmers who have successful bore wells today are those who own more land, which not only provided them resources to attempt several borings but also the larger extent of the land accommodated multiple boring attempts. Thus, well irrigation which was accessible to many farmers about ten years back through dug wells is now restricted to fewer bore well farmers, who generally own more land.

Equity Implications

In Alur watershed, out of the 66 farmers interviewed 55 cultivated betelvine in an area of 24 ha (0.4 ha per farmer) under dug well irrigation about one decade back. As against this, at the time of field study betelvine was grown by eight farmers in an area of 10 ha, averaging 1.25 ha per farmer. Even among the eight farmers, four affluent farmers were growing this lucrative crop in 8.5 ha. Thus benefits of high value crops under well irrigation are derived by fewer farmers now who are cornering substantial amount of groundwater, creating serious equity problems in the distribution of this scarce resource.

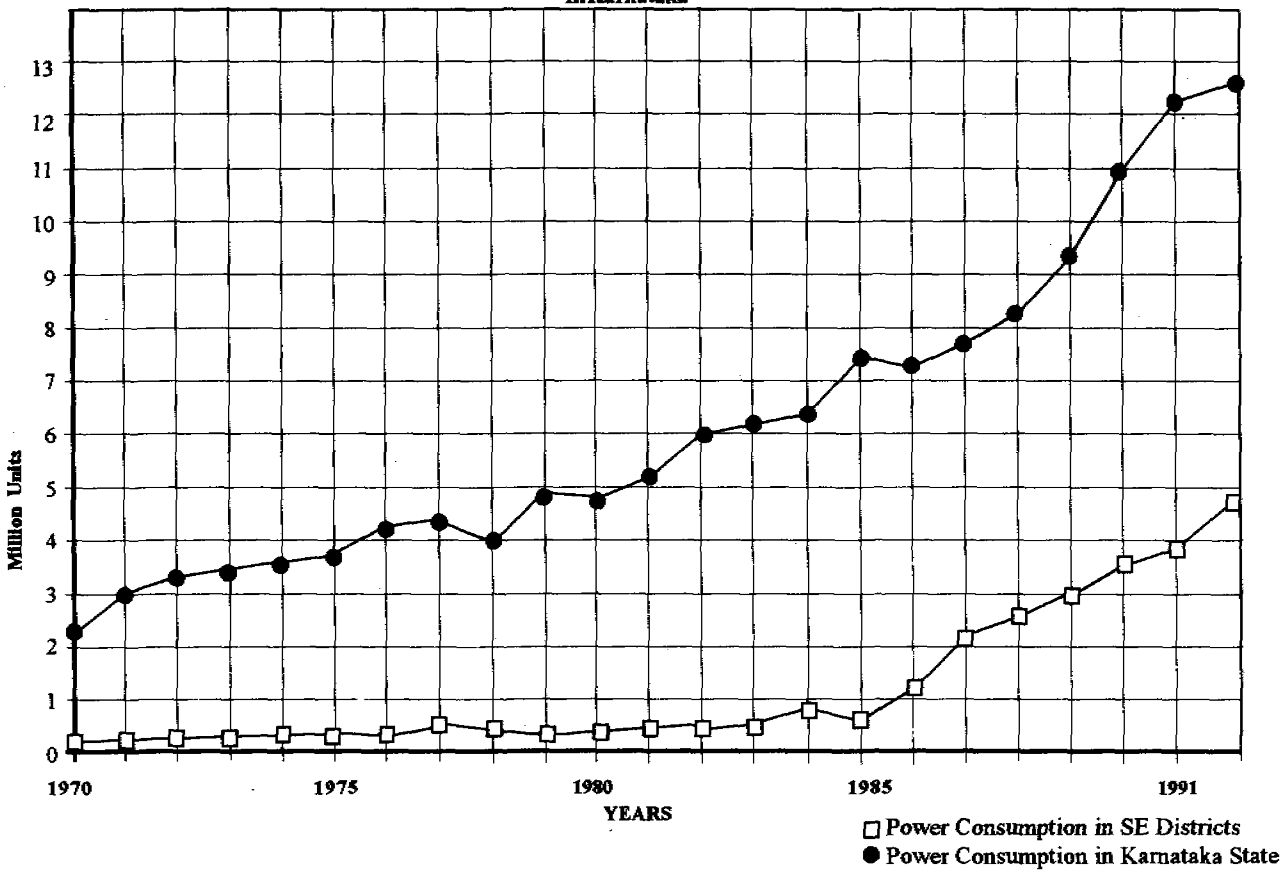
EMERGING ISSUES

Groundwater development trends in the study area are representative of the conditions prevailing in several low rainfall hard-rock areas of Karnataka, particularly in the four

Fig-4

Trend of Power Consumption

In Karnataka



southeastern districts. The following issues emerge out of the study of the two watersheds which deserve a wider attention and suitable policy shifts to ensure sustained groundwater irrigation.

At present assessment of groundwater is made based on water levels monitored in dug wells. These levels are not representative because most of the irrigation structures, particularly in the southeastern districts, are bore wells. Therefore, more observation bore wells should be constructed and monitored regularly for representative water levels.

Groundwater assessment is presently made on a block basis. It is essential that micro level studies are taken up within small watersheds as units. Groundwater availability may appear to be very encouraging in a block, but within the block there may be several small watersheds which are overexploited. To cite an example, Alur watershed is highly overexploited but the assessment of Davanagere block in which it is situated shows considerable potential for further development (Davanagre is classified as a white block where hardly 23% of the utilisable recharge is developed). The reverse is also possible. There may be several dark blocks having potential watersheds. Only micro level studies can bring out such features.

Water level decline has rendered several thousands of dug wells dry in the low rainfall hard-rock areas of Karnataka, particularly in the southeastern districts. As a result, investment in dug wells along with centrifugal pumpsets has become infructuous. Large numbers of bore wells constructed subsequently have also become infructuous due to declining water levels, forcing the farmers to redrill deeper bores. Declining water levels have reduced saturated thickness and consequently transmissibility of the aquifers and therefore, unless pumping is drastically reduced, the rate of water level decline will be much more rapid in the future. This will result in infructuous bore wells in these areas as it happened to dug wells. In such eventuality it is not possible to construct still deeper bore wells because most of these structures have already touched the bedrock, below which it is unproductive to drill.

In the absence of technical guidance, farmers are locating bore wells unscientifically and drilling them much deeper, below the productive zone, in search of stray fractures and incurring considerable wasteful expenditure. There is a need for sound technical advice to farmers so that bore wells are located correctly and designed optimally.

Bore well is an efficient groundwater structure which has several advantages over the conventional dug wells. However, unplanned growth of these structures can be hazardous, as noticed in the study area. In the absence of groundwater legislation in the country, the only way to regulate bore well construction is through energisation programme. The stage of groundwater development of an area must therefore be considered while drawing the energisation programme. Flat tariff and free power supply have encouraged farmers to use groundwater excessively and inefficiently even in groundwater scarce areas.

In view of the vast gap between power generation and demand, poor quality power is supplied due to which electric pumpsets are frequently damaged causing recurring expenditure and inconvenience to farmers. Many farmers in the study area responded that they were prepared to pay up to Rs.0.30 per kwh if quality power is supplied at regular timings.

Switching over to widely spaced horticulture crops and irrigating them by drip irrigation will help to cut down pumping and stabilise water levels. The State Government may consider subsidising cultivation of horticulture crops and water conservation measures in a big way in the water deficit areas of the state instead of spending enormous amounts in subsidising power supply which is only aggravating the problem.

Serious equity problems have emerged with the more affluent farmers remaining in the race for groundwater and the less endowed edged out and reduced to agricultural labourers. Disproportionately high quantum of groundwater is cornered by the lucky farmers who have successful bore wells.

Farmers must be made aware that groundwater is a common resource and the right to water need not go with the ownership of land. It has become necessary to train farmers in the management of this common asset by organising them into water user associations. Group pressures will probably be more effective in ensuring equitable distribution of groundwater.

The steady increase in the cost of bore wells and pumpsets and decrease in the landholdings have deprived many marginal farmers of well irrigation. It has become essential to promote the concept of group loans for wells, without which the weaker farmers will not be able to avail of loans individually.

In several villages of the southeastern districts of Karnataka groundwater is the only source of drinking water. Water level decline has already rendered several drinking water wells dry. If pumping for irrigation goes unchecked, there is a strong possibility of several villages facing acute shortage of drinking water in the near future.

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Appendix I. Land ownership, Cropping Patterns and Investments in DW, Alur & Chikkashivarah Watersheds

Sl. No.	Land Owned (acres)	Water-shed	Investment Since DW Became Dry (rupees)	Cropping Pattern (area in acres)			Perennial	Net Income (Rupees)	Remarks
				Year	Kharif	Rabi			
1	4	AWS	90000	1982-83	ragi (6)	vegetables (4)	-	30000	Farmer switched over to dryland cultivation as all his attempts to construct a BW failed.
				1992-93	ragi (8)	-	-	16000	
2	8	AWS	56000	1982-83	cotton (4)	groundnut (4)	-	16000	BW operating at a discharge of 2 lps since 1982-83enabling the farmer to cultivate betelvine which he could not do due to inadequate supply of water.
				1992-93	ragi (4)	groundnut (1)	betelvine (2)	53250	
3	3	AWS	40000	1982-83	jowar (1)	-	betelvine (2)	30800	BW is operating at reduced discharge of 1.25 lps. Hence area under betelvine was reduced to 1 acre as compared to 2 acres under DW irrigation.
				1992-93	jowar (1)	vegetables (0.5)	betelvine (1)	27350	
4	4	AWS	46000	1982-83	ragi (2)	wheat (2)	-	4800	Due to sharp decline in discharge from 2.5 to 1 lps farmer is unable to cultivate intensive crops like betelvine.
				1992-93	ragi (2.5)	wheat (1)		-7000	
5	2.5	CWS	25000	1982-83	ragi (1.5)	vegetables (1)	-	6400	Farmer switched over to dryland farming after the BW attempts failed.
				1992-93	ragi (2.5)	vegetables (1)	-	2875	
6	2	CWS	26000	1982-83	ragi (2)	vegetables (2)	-	12000	As the BW attempts failed farmer switched over to dryland cultivation.
				1992-93	ragi (2)	-	-	4000	
7	10	CWS	10000	1982-83	ragi (6)	vegetables (4)	-	30000	Farmer switched over to dryland cultivation after all the 11 attempts to drill a BW
				1992-93	ragi (8)	-	-	16000	

*BWGS

FORWARD TO BACKWARD AGRICULTURE: A STUDY OF INTENSIVE WELL IRRIGATION IN KOLAR DISTRICT OF KARNATAKA

S. T. Somashekara Reddy

Abstract

The study identifies the causes of groundwater depletion and the response of farmers in terms of crop selection. In Kolar district, wells and surface tanks are hydrologically linked. Water was, until recently, stored in tanks and this, even in summer months, contributed to groundwater recharge. Destruction of catchment areas caused siltation in most tanks and reduced their dependability as sources of water supply. As a result, wells became the primary dependable source of water supply. When tubewells were introduced, their numbers rapidly grew. This resulted in both flows into tanks and the recharge from them being intercepted. As a consequence the water supply reliability of tanks and dug wells further suffered. Tube wells are now the only reliable source of water supply and the water table has declined substantially.

With the decline in water levels, there is a shift to low water consuming crops. Vegetables have given way to food grains which are normally grown in dry lands. Few new techniques of water management have evolved to address scarcity. As a result, the area irrigated is declining.

In the absence of loans from the government to dig wells, farmers take crop loans to establish grape orchards and use the money to sink tubewells. However, the poor who were dependent on tanks and dug wells are rarely able to obtain these loans and have lost access to groundwater resources.

To remedy groundwater overdraft problems in a low rainfall region like Kolar, integrated ecological approaches are required rather than legislative or technical controls. Tanks which were sources for groundwater recharge have to be rehabilitated. Sinking of tubewells even with private funds has to be regulated. People's participation is required to control the number of wells, area to be irrigated and distance between the wells. To do this it is essential to designate groundwater as a common property, since every section of society is being affected by the depletion.

INTRODUCTION

In India, since 1950-51 the area irrigated from canals has increased from 7.2 million hectares to 14.8 million hectares. The real expansion in irrigated areas has, however, occurred through private investment in wells. From 6.0 million hectares in 1950-51 irrigation through wells expanded to 19.1 million hectares by 1982-83, an almost threefold increase (Table 1). Unfortunately dug wells, which were critical to the success of the Green Revolution in the initial years, did not expand as rapidly as tubewells (Table 1). By 1980-81, there was relative decline in the area irrigated by dug wells and enhancement in the area irrigated by tubewells. The percentage area irrigated by dug wells declined from 29% in 1960-61 to 20.7% in 1980-81. This decline has been attributed to declines in groundwater tables throughout the country. The decline is from five metres to ten metres (Table 2). These declines are supported by the Departments of Mines and Geology in the concerned States declaring districts in each region as 'dark areas' where, according to the their estimates, groundwater extraction exceeds recharge. In such dark areas credit for well construction and electrical connections for pumps are restricted in order to contain the net groundwater draft within the limits of recharge. Both the Central Government and States are drafting legislation to control the number of wells that can be operative in an area and their extraction capabilities (Karnataka 1984).

Table 1. Percentage of Area Irrigated by Wells in India

(Million ha)

Year	Area Irrigated by Dug Wells	Area Irrigated by Tubewells
1950-51	6.0 (28.7)	-
1960-61	7.2 (29.0)	0.2 (0.8)
1970-71	7.4 (23.7)	4.5 (14.4)
1975-76	7.6 (22.0)	6.8 (19.7)
1976-77	7.7 (21.9)	7.4 (20.6)
1977-78	8.0 (21.9)	7.6 (20.8)
1978-79	8.3 (21.8)	8.2 (21.6)
1979-80	8.5 (22.1)	9.3 (24.2)
1980-81	8.2 (21.0)	9.5 (24.9)
1981-82	8.2 (20.7)	9.9 (24.9)
1982-83 (Provisional)	8.4 (21.0)	10.7 (26.8)
Annual rate	1.1	19.8

Percentage of the net irrigated area is in brackets.

Table 2. Magnitude of Groundwater Decline 1976-1986

State	Area Where Decline is Observed	Extent of Decline	Observation Period
Andhra Pradesh	Parts of Kurnool, Prakasam Cuddapah, Amantapur, Chittor Mahaboubougar and Nalgund districts	Less than 1 metre to 10 metres	1976
Haryana	Parts of Faridabad, Gurgaon Karnal, Nabindargarh, Kuru-kshatre and Sonepat districts	0.5 to 4.0 m	1976-86
Gujarat	Parts of Bhavanagar, Mehsana Gandhinaggar, Ahmedabad, Jule-gesh, Amreli, Rajkot and Surendranagar	2 m to 5 m	1976-86
Karnataka	Kolar, Chitradurga, Raichar Bellary, Rijayuy, Chikkamagalur Bangalore and Dharwar	1 m to 5 m	1980-86
Maharashtra	Parts of districts of Ahmed-nagar, Aurangabad, Dhule, Beed Jalua, Masik, Amaravathi, Jalgman, Pune, Sangali, Ommann-bad, Satara and Shelapur	0.25 to 4 m	1982-86
Punjab	Parts of Amritsar, Hoshieryur Jalandhar, Patiala, Ludhiana Ruparagar, Sangrer and Kapurthala	0.5 to 4 m	1978-86
Rajasthan	Jaisalmar, Jhunjhunu, Sikar Nogaur, Jodhpur, Jaipur Ahoor, Barmor, Jahoal, Pali and Ajmer districts	0.16 to 7.3 m	1978-86
Tamil Nadu	Parts of Dharmapuri and Penanatrapuram districts	0.2 to 2 m	1982-86

Source:CMIE (1989), Basic Statistics relating to the Indian Economy, Vol. 2 States: Sept. 1989. Bombay.

Table 3.Percentage of Area Irrigated by Various Sources in Different States of India, 1984-85

State	Sources of Irrigation			
	Canals	Tanks	Wells	Others
Assam	3	-	-	37
Andhra Pradesh	51	22	24	3
Bihar	36	5	38	3
Bengal	37	14	36	13
Gujarat	19	2	79	-
Karnataka	42	19	27	12
Maharashtra	21	14	58	7
Madhya Pradesh	42	7	43	8
Orissa	59	18	23	-
Punjab	39	-	61	-
Rajasthan	33	4	62	1
Kerala	36	14	13	37

Among the states facing a decline in groundwater levels, Karnataka and Andhra Pradesh in the South and Rajasthan and Gujarat in the North are prominent. Unfortunately these states have extensive drought prone and desert areas. In these areas the availability of groundwater per unit of land is only two-fifths the level found in the north of India. In Andhra Pradesh and Karnataka the area irrigated by wells is only 24% and 27% respectively of the total irrigated area (Table 3). In contrast, in Gujarat and Rajasthan, wells irrigate 79% and 62% respectively of the total irrigated area. The decline in groundwater tables in Andhra Pradesh and Karnataka despite the low percentage area irrigated by wells raise a question — why should the small area irrigated by wells lead to large declines in the water table? Is it a case of overexploitation of the resource by the few who already own wells? Or are there other factors responsible for the decline?

While looking for answers to the above questions it is pertinent to note that tanks were a major source of irrigation in these states, as in the entire South, prior to the 1970s. Although these tanks were intended primary as surface water reservoirs for irrigation supply purposes, they helped to enhance groundwater recharge (Reddy 1991). Therefore the status of these tanks and their role in groundwater recharge must be examined if the decline in groundwater levels is to be understood. In addition, changes in the land use pattern in such areas could also have affected groundwater levels by reducing soil moisture (Bandhyopadhyay 1989). An attempt is made in this paper to examine the role of indigenous mechanisms in recharging groundwater, the factors responsible for their decline, the impacts of such decline on the farming community and the communities' responses to the decline.

In order to examine the relationship between surface reservoirs, tanks and groundwater levels, Kolar District in Karnataka has been selected as a case study area. This district has the highest area irrigated by wells in the state and six out of eleven talukas in the district have been declared as dark areas. Information was collected from three villages in the district to examine farmers' decisions regarding crop choice and the area to irrigate.

Kolar district is situated in the rain shadow region of the Western Ghats. It receives an annual average rainfall of 730 mm. Of this, 52% occurs between June and September and 29% falls between October and December. On average 47.6 rainy days occur each year and 54% of these are in the period June to September. An additional 28% of the rainy days occur in the period October to December. For the rest of the year rainfall is insignificant. Geologically, Kolar District is underlain by hard-rock formations and most groundwater is confined to the weathered zone.

In the early part of the century, Kolar district had one of the largest numbers of wells and area irrigated by wells of any district in the state. Well irrigated areas grew steadily until the early 1970s. During 1912-13, wells irrigated an area of 5883 hectares; by 1937-38 this had increased to 10436 hectares and by 1956-57 wells were irrigating 12040 hectares. In 1964-65 the area irrigated by wells was 16160 hectares and in 1970-71 it reached a peak of 36275 hectares. This declined to 34920 hectares in 1975-76. Since then, well irrigated areas have declined steadily. In 1980-81, 26572 hectares were irrigated from wells and by 1984-85 the area irrigated by wells had declined to 24557 hectares.

Until 1979, the water table in wells on the borders of Kolar district followed the rainfall in the expected manner (Rama Prasad 1987). Thereafter even during good rainfall years such as 1981, the water table did not recover near the surface as it had before 1979. Based on those findings Rama Prasad concludes that "there is overexploitation of groundwater." If there was overexploitation then the area irrigated by the wells should have been enhanced. On the contrary, as shown earlier, there is a decline in the area irrigated by wells right from 1974-76. However there was an increase in the number of wells and in the number of pumpsets (Table 4). This increase should not be construed as a source for overdrafting, as the evidence of area irrigated by wells is against such a conclusion. When the area irrigated by the wells has not expanded to prove overexploitation, then the possible way of utilising the water drafted by the wells and power-run pumpsets should have been consumed within a limited area for growing more than one crop. An examination of the area irrigated more than once (Table 5) by wells in Kolar district does not prove any enhancement in the area irrigated by the wells. In fact the area has been reduced. This reduction in the area irrigated more than once proves that there is no factual information to believe that with an increase in the number of wells there is an enhanced drafting of water. In fact, it is indicative of the inability of the newly dug wells to irrigate more than one crop.

Table 4. Number of Wells and Pumpsets in Kolar District

Year	No. of Wells	Pumpsets	
		Electrical	Diesel
1960-61	22719	NA	NA
1965-66	29903	20368	NA
1975-76	49697	39368	NA
1980-81	50859	48438	49
1984-85	59450	59248	2061

Table 5.Area Irrigated More Than Once in Kolar District

Year	Area (hectares)
1969-70	38,392
1972-73	29,493
1977-78	30,719

Source: Arakari, H.R. et al. (1967): Soil Management in India. New Delhi: Asia

If the new wells were not helpful in growing more than one crop, it is possible that declines in the water table are due to farmers planting water intensive crops (Bandhyopadhyay 1989). To examine this possibility, cropping patterns in the well irrigated areas of Mulabagal Taluk (a 'dark area') were examined. In this taluka there has been a gradual movement from high water consuming crops to low water consuming crops. The well irrigated area under rice has declined from 1693 hectares to 431 hectares. Similarly, the area under sugarcane has also been reduced from 453 hectares to 168 hectares. Finally, the area under other crops such as potato and vegetables has been reduced. Only in the case of mulberry is there an increase in area (from 425 hectares to 762 hectares). Mulberry requires little water and is known for drought resistance. The observed crop shifts from high water consuming to low water consuming crops (Table 6) prove that the new wells and the water drafted from such wells is not utilised for raising high water consuming crops.

Table 6. Cropped Area Irrigated by Wells in Mulabagal Taluka

(hectares)

	Year	
	1970-71	1985-86
Net area irrigated by wells	3462	2180
Rice	1683	401
Jowar	138	35
Ragi	900	972
Maize	155	75
Groundnut	401	17
Sugarcane	453	168
Potato	179	12
Chilli	60	18
Vegetables	364	155
Others	711	531
Mulberry	425	762

If the new wells are not used to grow crops which consume large amounts of water and they have not been used to increase cropping intensities, then doubt arises concerning the possibility of groundwater overdraft. The probability can be that the increase in the number of wells might have reduced the yield from each well, as the available quantum of groundwater is shared by each well. Such sharing must have reduced the amount of water that could be drafted out of each well. This must have compelled the well-owners to grow only those crops which consume less water. When the quantum of water available declined, well-owners first shifted to crops which demand less water and second, they might have also reduced the irrigated area.

The idea that declines in the available groundwater are due to sharing of the resource by the old well-owners with the new well-owners appears untenable since the area irrigated by wells shows a progressive decline and there were wells which were totally abandoned due to insufficient yield of water. In Mulbagal taluka alone the number of such abandoned wells increased from 120 in 1980-81 to in 1985-86. Similarly, in the district of Kolar as a whole there was an increase from 1481 abandoned wells in 1981-82 to 4822 wells in 1984-85. The number of abandoned wells may not be equal to the number of wells constructed; even then the area irrigated by wells should not have decreased if the new wells are drafting higher quantum of water than recharge.

The regular decline in groundwater levels is normally attributed to the arrival and proliferation of tubewells in large numbers (Chaturvedi 1987). However, what is forgotten is that the very appearance of tubewells is a response to the decline in groundwater levels and not vice-versa (Reddy 1989b). When the levels of groundwater could not be reached through dug wells even at depth of 40 to 50 metres, the farmers of Kolar District had no other option except to go in for tubewells. Dug wells of greater depth would collapse. In this situation, tubewells proved beneficial to the farmers of Kolar District.

Historically in Kolar District most irrigation from wells occurred adjacent to or in the command area of tanks. The wells supplemented water available in the tanks in summer months and in times of crisis. The tanks were simply embankments thrown across valleys in order to store water (Sharma 1982 in VanOppen & Rao 1982). In this regions where the rainfall is below 750 mm, every drop of water saved helped to conserve water in the form of soil moisture and also contributed to groundwater. Tanks are present in almost all valleys suitable for their construction. Kolar District has 3692 tanks. Of these, 3320 tanks irrigate less than 50 acres and 372 tanks irrigate over 100 acres. According to an estimate when tanks overflow in Kolar District they submerge nearly one-fourth of the geographical area (Raj Iyer 1989). Such submergence enhanced groundwater recharge. The existence of wells in the command area of tanks was helpful in two ways: (1) to exploit the groundwater stored in the soils that might have cause waterlogging and (2) to irrigate areas outside the tank's command. This ensured that water stored in the rainy season could be utilised in summer months.

In Kolar District, farmers have various strategies for making water available for irrigation beyond the summer season. Popular methods include: allocating water in the tank on an hourly basis; restricting crop selection to paddy varieties which require only 4-6 waterings, not allowing puddling as part of field preparation, and growing rainfed crops in summer months in the command area of tanks. Another method called 'damasi' is practiced in the post-monsoon season. In this, farmers reduce the area individuals plant in proportion to the water available in the tank. Irrespective of land ownership all farmers cultivating crops in the command area of the tank grow their crop in a location convenient for irrigation (Reddy 1989a). Utilising these mechanisms the farmers are successful in harvesting a crop in summer months.

The above systems indirectly increased the availability of water even in summer months for percolation purposes. Increased percolation in turn helped in maintaining groundwater levels. Finally, the absence of pumps limited the amount of water drafted on a daily or seasonal basis to that extractable either manually or through animal power. As a result the depth of the groundwater was always close to the surface. In this situation the depth of water in wells fluctuated according to the rainfall pattern and levels of water in tank. When the rainfall was below normal the tanks were helpful in making the received low quantum rainfall to percolate into the soil, to maintain the levels of groundwater.

Today, tanks in Kolar district seem to be losing their capability to store water or to irrigate. In 1912, tanks in Kolar District were irrigating 32035 hectares, by 1937-38 it had been enhanced to 36047 hectares, even in 1964-65 they were irrigating 34324 hectares, by 1970-71 it was 36275 hectares, by 1980-81 it had been reduced to 32219 hectares. This has been further reduced to 30210 hectares by 1984-85. This reduction in the capability of tanks is in a way indicative of reduction in the quantum of water available for percolation or for recharge of groundwater. The consequence of such reduction can be seen on the flow of streams in the district. The gauging of flow of water in the Pinakini streams of Kolar District has been disbanded long back as the flow at almost all points of gauging has dried up and the flow is almost absent throughout the year (WRDO-K 1989). This is also reflected in the area irrigated by the canals, which were diversions from such streams.

Apart from tanks there were other mechanisms for enhancing groundwater recharge. Structures called **Katte** and **Kunte** were common in the catchments of almost all the tanks and in between cultivated fields. These were helpful in holding back surface runoff to increase percolation. **Kunte** were small embankments across the flow of water in catchment areas or in-between fields. Similarly, **katte** were small embankments receiving water from **kunte** and the surrounding area. At no time, were **kunte** used for irrigation purposes but **kattes** were used for irrigation in times of crisis or when the storage capability of a structure was very high. These structures being located at various strategic points in and around each tank helped not only in the groundwater recharge but also helped in arresting the flow of silt into tanks. These structures were desilted every year by the community before the onset of each season.

Katte and **Kunte** were managed and regulated by the community and were integral part of the Common Property Resources (CPR) in and around each village. When the maintenance was beyond the capabilities of a community, the king or state used to extend a helping hand. With the arrival of the English, these structures had to be totally managed by the community or by a group of villagers, as they were not regarded as beneficial for any revenue purpose (Reddy 1991). Furthermore, under a programme of extensive cultivation after 1940 and in the 1960s CPRs were distributed for purposes of cultivation (Jodha 1976). Such a distribution was a breach and a dishonor to the practice valid up to then. By such an act, villagers were made to realise that they are no longer the managers of CPRs. Such realisations actually slackened the participatory role of community in managing the CPRs especially in the management of Kattes and Kuntes. Therefore, once the catchment areas were distributed for cultivation purposes the kattes and kuntes were also ploughed in. As a consequence, the flow of rainwater was directly into the tank carrying along with it high quantum of silt from newly cultivated fields. Such silt deposits reduced the capability of each tank which, in turn, reduced the quantum and duration of water available for percolation and for recharging, which in a way has caused decline in groundwater level.

Today, Kolar district has lost not only the mechanisms that were helpful to recharge groundwater, but also has come to possess crops, especially eucalyptus, which affect groundwater recharge (Shiva and Bandyopadhyay 1984). Kolar district happens to be the biggest beneficiary under the Social Forestry Scheme. According to information provided by the Forest Department of Karnataka, nearly 30,000 hectares of land is planted with eucalyptus. It is argued that these trees do affect groundwater recharge since water which infiltrates is absorbed by the horizontal roots of eucalyptus before of it can reach the sub-surface (Shiva 1984). The observation that groundwater levels do not recover even after heavy rainfall may be due to the prevalence of eucalyptus on a large scale.

With the frequent droughts in the 1960s and 70s especially the severe one in 1976, special programmes were initiated in the form of bank loans to dig wells and to install pumps. This encouragement from government saw the multiplication in the number of wells fitted with power-run sets.

Such multiplication was not drafting excessive groundwater but was sharing what was already available. As a result the levels receded beyond the levels of power-run sets. The response of the farmers to such decline was by deepening wells till the required quantum was obtained. Farmers continue this process of deepening year after year till the available water is sufficient to raise a crop in the summer. When such deepening was not successful in increasing well yields, the farmers were forced to raise crops only in rainy season or to ration available water. The arrival of tubewells did help to tap water available beyond the zones of dug wells. Therefore, the tubewells were an answer for the levels of groundwater which was already declining.

A few villages in the 'dark area' of Siddalaghatta taluka in Kolar district were studied in 1986 in order to examine how changes in pumping technology affected water levels and how with every decline the farmers developed strategies to meet the shortage of water, . The villages selected for the study are located in the watershed of Muthur tank. In this watershed there are three tanks: Kanithalli tank (43 ha), Muthur tank (60 ha) and Mallur tank (90 ha). There are six villages in the watershed which share the water in these tanks: Kanithalli, Thimmanahalli, Ganganahalli, Muthur, Kambadahalli and Mallur. The number of wells in each village and the area irrigated by other sources between 1965-66 and 1984-85 are provided in Table 7. The Table shows that the area irrigated by wells increased up to 1980-81. After this there was a decline in the area irrigated by wells and by 1984-85 the area irrigated by wells decreased to a level far below the levels of 1965-66. This drastic decline was examined from the point of view of the factors responsible for the decline and the people's response to such declines.

The catchment of Kanithalli tank is in Kanithalli itself, which is also its beneficiary. Thus Kanithalli is in the catchment of Muthur tank and the surplus from Kanithalli tank flows into Muthur tank and surplus from Muthur flows into Mallur, thus forming a link or part of the chain. Since 1965-66, these tanks have not received sufficient water to irrigate even a single khariff crop. In addition, there has been insufficient water to grow crops other than paddy. In recent years, even the area under paddy irrigated by each tank has decreased.

The major catchment for the Muthur tank is in the high lands beyond Thimmanahalli from where two canals bringing in rainwater originate. Beyond this region is the Gollapudi Kaval, a forest area which gives rise to another big canal linking Muthur tank. On the way, each canal fill up a Katte before reaching the main tank. Similarly the Kanithalli tank had its source from the gomal lands from one end of the village, beyond which were the forests called Sambargiddada Kaval. These forests also had a link to Muthur tank.

Timber in the gomal lands and the forests beyond these lands was harvested by the Government at the time of the Second World War for making charcoal. Between 1965-70 the Forest Department replaced natural regeneration in the forests with eucalyptus plantations. Much of the gomal lands were given away for cultivation purposes under the programme of extensive cultivation after 1940. Later on, in 1960, the entire gomal land was distributed to landless families in the villages of Thimmanahalli, Lingadhalli and Kanithalli. In the first phase of release for extensive cultivation it was rich farmers who had good contacts outside the village especially with the bureaucracy who obtained the most fertile land. The poor got the lands on the table top of the contour. Such rich farmers who could encroach gomal lands had owned lands irrigated by wells in the foreshore of the area of Muthur tank. With the decline in the ability of tank to hold water up to the levels of overflow and even in summer months, these wells which were dug only up to 30 to 40 feet started yielding less water. Once they reached the point of very low return, these rich farmers could not deepen wells beyond 10 to 20 metres as they used to strike semi-solid soil which used to cave in, endangering the life of the workers who are deepening the well. To avoid such dangerous situations, the rich farmers had to go in for wells in the lands they had acquired in the gomals. As these lands were in an elevated place compared to the lands in the foreshore area of Muthur tank, the rich farmers initially went in for dug wells, but when they failed to strike water even beyond 50 metres they were forced to go in for tubewells.

Farmers who drilled tubewells for irrigation often could not strike sufficient water even after spending large amounts. Most of the amount spent on tubewells were private loans raised by each farmer, since the government was not financing wells which did not respect minimum spacing distances. Because of losses the rich farmers were in need of financial assistance from the government to repay the loans raised privately. The only type of assistance capable of providing sufficient finances to repay loans raised privately was through government supported loan schemes for grape cultivation. Under these schemes, Rs. 1,87,000 was provided as a loan for each hectare of grapes planted. Farmers were particularly interested in 'seedless' varieties because that was bringing in huge profits. As a result, rich farmers who had drilled tubewells in the catchment area of Muthur tank planted grapes.

In contrast, lands cultivated by the poor were ploughed every year since no loan assistance was forthcoming. For the poor to obtain loans for digging wells or pumpset purchases, government rules stipulated that they must own at least two hectares of land at the place where a tubewell was to be established. As a result no loan could be allotted to landless people or small farmers. They had to grow only rainfed crops. As years passed the poor had no other way to survive than to illegally sell their lands to rich farmers or to fallow the land as the yields decreased after few years of cultivation due to high rates of erosion.

Those rich farmers who had planted grapes had to make new water courses to prevent surface run off within their lands. Such newly erected bunds on the boundaries of each plot of grapes cut prevented surface runoff to the old water courses which used to carry water into tanks. The new courses diverted the water from Muthur tank into a big canal passing through Kambadahalli. Such diversions were made even for Kanithalli tank and diverted the runoff away from the tank. Due to several such diversions, tanks in Muthur watershed lost their source and have not overflowed since 1965-66.

In addition, with the arrival of power-run irrigation pumpsets, farmers adjacent to tanks were able to tap the stored water through their wells. This reduced the amount of time water was available in tanks each season. The relationship between groundwater extraction and water stored in tanks is not known to local people. For them, groundwater and surface water are viewed as independent. Therefore when the tank failed to hold water in sufficient quantity even for a single crop the tank was encroached for the purpose of cultivation by those who own land in the foreshore area. This further reduced the holding capability of a tank.

Once it became impossible to irrigate even a single crop in the command areas of each tank, the lands were converted, initially, into rainfed lands and later on to groundwater irrigation. Wells were dug or tubewells drilled in the old tank command areas, both for local irrigation and as a source of water for crops in distant locations. Often farmers pump water from wells in the tank's command areas into wells which have gone dry and are located in faraway fields or in the midst of a garden or orchard. Such horizontal transfers of water take place even in the rainy season as most of the wells in the upper reaches have gone dry.

The above changes in irrigation had adverse consequences on the storage capability of tanks and cropping pattern in the command areas of each tank. Between 1965-66 and 1975-76 two prominent changes occurred in the crops irrigated from wells. First, there was a shift from food grain crops such as ragi to newly introduced High Yielding Varieties (HYV) such as maize and jowar and the area under vegetables increased. Second, the area under mulberry decreased (Table 6) along with numerous other crops. In a way it was a shift from multiple crops to only few crops which are consumed by the external markets.

Between 1975-76 and 1985-86, cropping patterns shifted again. Vegetables gave way to ragi and food grains like maize and jowar. There was also a shift to plantation crops such as grapes. In other words, there was a shift back to less water consuming crops and once again the food grain crops dominated over commercial crops. Even the area under mulberry saw further reduction. In one of the villages, Kambadahalli, the mulberry crop was totally left to survive under rainfed condition. A few of those who were unable to irrigate any crop changed to eucalyptus.

In addition to changes in cropping patterns, farmers are adopting water saving techniques for irrigation. The method adopted to raise mulberry is illustrative. In mulberry fields, the land is fragmented into several sections capable of yielding leaf to feed at least 50 silkworms (below which it is not economical). Each section is irrigated in rotation so as to maintain the plants in the entire field. Normally, one-tenth of an acre is the ideal size for the fragment. Within each fragment, there will be several divisions based on the amount of water available in the well. Depending on the water availability, each division will be watered both in the morning and evening. To irrigate the crop when the water availability is very low, only the top soil is wetted to compensate for the loss of moisture due to evaporation. Normally this is done in the evenings to allow the plants to consume as much of the moisture as possible. Another method is to irrigate each furrow once a week with an equal quantity of water. In this method, each day a few rows or furrows can be irrigated. Sometimes, depending upon water availability, the number of furrows that can be irrigated each day is determined. Similar methods are adopted to irrigate ragi as well as grapes.

To grow something with less amount of available water, farmers are often forced to choose between crops with low monetary returns but that lead to self-sufficiency in terms of food grains, or crops which can bring money as profit but require more water. Grapes are the prime exception to this. They require less water but can yield high profits. As a result, the area under grapes has seen an appreciable increase (from one hectare to 15 hectares) between 1965-66 and 1984-85. A similar increase occurred in other villages also.

In order to enhance the availability of water in the wells, owners frequently drill tubewells within dug wells. Normally, in the villages under examination and in Siddalaghatta taluka of Kolar District wells are dug to depths of between 30 and 50 metres. Within such a well, a tubewell of another 70 to 120 metres will be bored. In Siddalaghatta area, the success achieved by tubewells is very low (roughly 1%). For this reason, farmers try even today to deepen their dug wells. Normally, such deepening takes place in the area away from the foreshore of the tank and it can even be in the catchment of the tank. This is to avoid the semi-solid soil closer to the foreshore area of the tank. To deepen wells which already have a depth of 30 to 50 metres, special instruments are developed. Normally, in the summer months there will be a big demand for these instruments. In actuality deepening does not tap groundwater but enhances seepage flow. The digging is carried out till a soft surface is reached or deepening is no longer possible. The position of wells in all three villages studied is given in Table 7.

The consequence of 566 wells in these three villages going out of use, as seen earlier, has changed the cropping pattern in the watershed of Muthur. The cropping pattern has changed from highly irrigated to rainfed. This change from rainfed to irrigation and back to rainfed crops can be termed as forward to backward agriculture.

CONCLUSIONS

In India, even though wells are becoming the dominant source of irrigation, throughout the country, groundwater levels are declining. Many claim that it is the sinking of tubewells on a large scale which has caused depletion. However, as experienced in Karnataka, the tubewells were a response to a situation in which dug wells were no longer feasible.

Claiming that groundwater levels are dropping due to extraction from wells fails to recognise how the destruction of surface tanks, which were the primary source of groundwater recharge, has compounded the decline. As the capacity of surface tanks declines due to siltation, the water management committees for each tank could not function due to resource scarcity. A free for all resulted which ultimately enhanced the process of decline in groundwater levels.

Due to the depth limitations on dug wells and infeasibility of tubewells in the area around tanks, many farmers were forced to go in for tubewells in the catchment area of a tank. Such wells with an independent command area either obstructed or diverted water from the tank which ultimately reduced groundwater recharge.

With the decline in groundwater levels there was a change in the cropping pattern -- initially from high water demanding crops to short term vegetable crops and later, with water yields reaching rock bottom, to mulberry. At the same time as this shift, techniques such as irrigating furrows on rotation or fallowing part of the mulberry garden were adopted to save water. Finally, wherever irrigation became unfeasible, farmers returned to rainfed cultivation. After going forward by irrigating lands, reverting back to rainfed cultivation represented a step taken backwards.

To address water table drops, restrictions on cropping pattern and overdrafting are not sufficient. A greater ecological approach, covering watersheds and including tanks or other systems for percolation, has to be devised. Such an effort has to be through people's participation. The users should be made to pay for the conservation, not necessarily in monetary terms but in terms of labour.

Table 7. Sourcewise Irrigated Area in Selected Villages

Sl. No.	Kanhadahalli					Gangenahalli					Kanithshalli				
	Wells		Tanks		Total Area	Wells		Tanks		Total Area	Wells		Tanks		Total Area
	No	Area	No	Area		No	Area	No	Area		No	Area	No	Area	
1) 1965-66	40	80.18	1	5.36	85.54	10	20.41	1	14.20	34.67	48	125.19	1	18.37	148.56
2) 1975-76	53	93.18	1	Nil	83.18	28	56.31	1	3.13	59.44	76	206.59	1	10.01	216.60
3) 1980-81	67	110.26	1	Nil	110.26	38	68.81	1	Nil	68.81	103	288.39	1	Nil	286.39
4) 1984-85	74	63.25	1	Nil	63.25	38	48.32	1	Nil	48.32	103	181.26	1	Nil	101.26

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NEED FOR REALISTIC ASSESSMENT OF GROUNDWATER POTENTIAL IN INDIA

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Abstract

Groundwater pumping for irrigation on a large scale started about three decades ago. Since the resources is of limited nature, it became necessary to plan and regulate its development and utilisation to the extent that it is replenished annually by recharge through various sources such as rainfall and canal seepage. Infiltration and water movement in different types of rock formations is a very complicated process. Several attempts have been made towards a quantitative assessment of groundwater potential and its status in conjunction with surface water over the last three decades. In this paper an attempt has been made to suggest a realistic process for the assessment of groundwater potential. Appropriate roles for various agencies and farmers in this respect are also discussed.

INTRODUCTION

Groundwater is defined (Todd 1959) as water in a saturated zone of a geologic stratum. Groundwater originates for all practical purposes as surface water. Water infiltrates into the ground from natural recharge of precipitation, stream flow, lakes and reservoirs. In addition, efforts by man constitute artificial recharge. Once underground, the water moves downward under the action of gravity. When a zone of saturation is reached, the water flows in a direction controlled by the hydraulic gradient. Discharge of groundwater represents a return of water to the earth's surface. Most natural discharge is into surface water bodies. Spring flow, evaporation and transpiration are other natural modes of discharge. Pumping from wells is the primary avenue by which man has created a new artificial source of discharge and, in the process, altered the natural discharge patterns. Usable groundwater occurs in permeable geologic formation known as aquifers. These permit appreciable amounts of water to move through them under usual field conditions. Thus it is clear that all the water that is stored underground cannot be used. For planning and development of groundwater it is therefore essential to assess the availability and consumption of usable part of groundwater.

DEVELOPMENT OF GROUNDWATER FOR IRRIGATION

The use of dugwells for irrigation has been practiced since ancient times. However, it is only since 1950 that development statistics are available. The progress of groundwater development up to 1975 (Jain 1977) and as indicated by the "All India Minor Irrigation Census" (MOWR 1993) for the year 1987 are given in Table 1.

Table 1. Progress of Groundwater Development (in millions)

	1950	1965	1975	1987
Dug wells	3.50	5.00	7.25	7.13
Shallow tubewells	0.003	0.02	1.00	3.99
Deep tubewells	0.002	0.012	0.024	0.104
Pumpsets	0.80	0.90	4.75	8.49
Area irrigated (Mha)	6.50	9.50	17.00	26.78

Although the above figures give a rough impression of the growth in groundwater utilisation, there is no system for keeping the actual record of groundwater structures constructed and how many of these are in use. The only attempt made so far was to organise a Minor Irrigation Census all over the country in the period 1987-92. Even this data set is incomplete since Rajasthan did not participate. Whatever data could be collected in this census (MOWR 1993) revealed that a large number of structures have gone out of use. Of the dug wells, 1,453,292 were out of use and the comparable figure for shallow tubewells was 41,046. Area irrigated estimates also differed between official sources and the census. The census gave a figure of 26.78 million hectares (Mha) at the end of 1986-87 as compared to Ministry of Water Resources figure of 28.49 Mha (MOWR 1989). Land utilisation statistics (Ministry of Agriculture) gave another figure of 27.78 Mha.

For the VIIIth Plan (1992-97), the Ministry of Water Resources has an ambitious plan to construct 1.71 million dugwells, 1.69 million shallow tubewells and 11,400 deep tubewells (Hindustan Times 1993). The area likely to be brought under irrigation by this is about 8.0 Mha. The total target for additions to irrigated area under the VIIIth Plan through minor irrigation programmes is reported as 9.36 Mha of which 8.0 Mha are from groundwater and 1.36 are from surface water sources (Planning Commission 1992). If this is achieved, it would amount to adding 1.6 Mha annually which is just double the target of 0.80 Mha for Major-Medium Irrigation Projects. The irrigation potential from groundwater by the end of 1993-94, as given in the Annual Report 1993-94 of the Ministry of Water Resources, Government of India, is 42.30 Mha which exceeds the officially estimated potential for irrigation from groundwater of 40 Mha The revised provisional figure for the ultimate groundwater irrigation potential is 80 Mha (Bhu Jal 1988). Neither 40 Mha or 80 Mha appears to be realistic assessments of the area which will ultimately be possible to irrigate from groundwater sources.

GROUNDWATER RESOURCE ASSESSMENT

Unlike surface water, little importance has been attached to groundwater resource assessment. The Working Group Report on Minor Irrigation for IVth Plan (1969-74) issued by the Ministry of Food and Agriculture in 1969 stated that no dependable assessment had been made of groundwater resource in the country. A very rough assessment of groundwater resources (Irrigation Commission 1972) was attempted by Dr. K. V. Raghva Rao and his colleagues at the Central Groundwater Board (C.G.W.B.). According to this estimate the net groundwater recharge was 218.8 million acre feet (270,152 m cum) and the annual draft at the end of 1967-68 was 46.76 million acre feet (21.4%). The Irrigation Commission commented that Dr. Rao and his colleagues at the CGWB excluded the draft of wells used for domestic and industrial use in working out the total groundwater draft. This may be on the order of 65,000 million cubic metres (m cum). The groundwater thus available for future irrigation and domestic use at that time was on the order of 204,000 m cum. Subsequently usable groundwater for irrigation was estimated as 11 Mha m in 1974, 21 Mha m in 2000 and 26 Mha m in 2025 (Agriculture Commission 1976). Based on the figure of 26 Mha m as the amount of groundwater available if the resource was fully developed and 0.65 m as the average depth of water required for irrigating one crop, 40 Mha was adopted as ultimate irrigation potential for groundwater in the country.

Recently, the amount of groundwater estimated to be available for irrigation has been revised to 38.20 Mha m and the area it will ultimately be possible to irrigate, to 80 Mha (provisional) in place of 40 Mha (Working Group on Minor Irrigation 1989). These figures are, however, being accepted as accurate. For example, the Ministry of Water Resources in a written reply to Parliament on 5.12.92 (Bhu Jal, Sept. 1992) stated that the ultimati irrigation potential from groundwater is 80.38 Mha of which the irrigation potential created and utilised at the end of the VIIth Plan (1989-90) is 34. 80 Mha and 32.5 Mha respectively. About 43.3% of the groundwater irrigation potential was tapped by the end of the VIIth Plan.

The status of the groundwater balance was first published in Bhu Jal in October 1988. The statewise details revealed a huge untapped irrigation potential in twelve major states: Andhra Pradesh - 4.15 Mha, Assam - 1.52 Mha, Bihar - 5.48 Mha, Gujarat - 3.19 Mha, Karnataka - 2.42 Mha, Madhya Pradesh - 11.20 Mha, Maharashtra - 4.52 Mha, Orissa - 5.15 Mha, Rajasthan - 2.18 Mha, Tamil Nadu - 1.90 Mha, Uttar Pradesh - 6.50 Mha, and West Bengal - 1.65 Mha, the total being 49.86 Mha. The amount of groundwater available for development is much more than what has been developed so far. For example, according to these figures, Gujarat could irrigate 3.19 Mha of groundwater -- more than one and a half the 1.8 Mha of irrigation potential (Patel 1991) to be created by Sardar Sarovar Project which will cost 134,000 million Rupees (Qureshy 1993). Similarly in Madhya Pradesh, the India Sagar Multipurpose Project on the Narmada which will cost about 14000 million Rupees will irrigate an area of roughly 0.123 Mha while groundwater potential available in Madhya Pradesh is on the order of 11.2 Mha. So why construct the controversial Sardar Sarovar and Indira Sagar Dam, when relatively much cheaper untapped groundwater resources are available? The annual rate of groundwater development in Gujarat is on the order of 0.025 Mha and that in Madhya Pradesh is 0.090 Mha which is extremely low compared to the potential. For Gujarat let us look at the districtwise groundwater balance (Bhu Jal News 1991) as given in Table 2. Table 2 indicates that even in chronically drought prone districts of Gujarat like Panchmahal, Rajkot, Kutch, Jamnagar, Bhavnagar, Ahmedabad, etc., there is substantial groundwater available for development. Even in districts covered under the Sardar Sarovar Project, considerable groundwater potential is available (see Table 3).

The case of Punjab contrasts with that of Gujarat. There, groundwater estimates made for the year 1989-91 reveal that out of 118 blocks 73 blocks are in dark category, 15 in gray and 30 white. Here dark means over 85% groundwater development, gray indicates between 65% and 85%, and white is for development levels below 65%. The state as a whole has utilised 98% of its groundwater resource potential, and six districts viz., Amritsar, Jalandhar, Kapurthala, Ludhiana, Patiala and Sangrur are overdeveloped. Observed water table trends do not support these estimates. Several areas show a rise in water tables and waterlogging (see Table 4).

Table 2. District Groundwater Balance in Gujarat (provisional)

Sl No.	Name of District	Equivalent Potential Available for Exploitation MCM/Yr	Crop Area that can be Irrigated with Applicable Water Depth of 50 cm (hectares)
1	Ahmedabad	819.53	163,906
2	Amreli	299.13	59,826
3	Banaskantha	825.04	165,008
4	Baroda	942.66	188,532
5	Bhavnagar	711.34	142,268
6	Bharuch	745.19	149,038
7	Bulsar	835.46	167,092
8	Dang	121.78	24,356
9	Gandhinagar	78.13	15,626
10	Jamnagar	469.78	93,956
11	Junagadh	556.80	111,360
12	Kheda	1354.26	270,852
13	Kutch	284.18	56,836
14	Panchmahal	792.99	158,598
15	Rajkot	518.85	103,770
16	Sabarkantha	607.11	121,422
17	Surat	1503.75	300,750
18	Surendra Nagar	464.48	92,896
19	Mehsana	313.57	62,714
		12,254.03	2,450,806

Source: Bhu Jal News, Jan-March 1991, C.G.W.B

Table 3. Untapped Irrigation Potential from Groundwater in Command Area of Sardar Sarovar Project (ha.)

	District	Irrigation Potential to be Created by S.S.P.	Undeveloped Irrigation Potential from Groundwater
1	Baroda	3,40,000	1,88,532
2	Ahmedabad	3,30,000	1,63,906
3	Surendra Nagar	3,04,000	92,896
4	Banaskantha	3,13,000	1,65,008
5	Bharuch	98,000	1,49,038
6	Mehsana	1,50,000	62,714
7	Kaira	1,16,000	2,70,852
8	Panchmahal	10,000	1,58,598
9	Gandhinagar	10,000	15,626
10	Bhavnagar	48,000	1,42,268
11	Rajkot	34,000	1,03,770
12	Kutch	37,000	56,836

Table 4. Anomalous Position of Groundwater Estimate in Punjab

	District	BlockWater	Level Trend
A. Dark Blocks Showing Rising/Steady Trends in Water Levels			
I.	Bhatinda	1. Phul	Rising
II.	Kapurthala	2. Kapurthala	"
		3. Nadala	"
		4. Phagwara	"
		5. Sultanpur	"
III.	Gurdaspur	6. Sri Hargobindpur	Steady
IV.	Jalandhar	7. Jalandhar	"
		8. Nawan Shahr	"
		9. Shahkot	"
V.	Ludhiana	10. Dehlon	"
		11. Lundhiana	"
		12. Macchiwan	"
		13. Mangat	"
		14. Sindhwanbet	"
B. White/Gray Blocks Showing a Declining Trend			
VI.	Ferozpur	15. Ferozpur	Declining
VII.	Hoshiarpur	16. Saroya	"
VIII.	Patiala	17. Dera	"
IX.	Sangrur	18. Sehna	"

Source: National Bank of Agriculture and Rural Development, Bombay

The above examples in Gujarat and Punjab prove that the present assessment of groundwater resources in the country cannot be said to be realistic or represent the picture on the ground. The Working Group on Minor Irrigation (MOWR 1989) made the following recommendations in this respect.

i) For more scientific assessment of ultimate irrigation potential, basin and sub-basinwise total water balance studies should be done.

ii) The present methodology for calculating groundwater potential utilises many parametres that are calculated on the basis of ad hoc norms. Actually the only physically observed parametres are water table fluctuations, pre- and post-monsoon. The methodology needs revision.

iii) The same methodology is used for alluvium and hard-rock areas. A more detailed and sophisticated study is needed for hard-rock areas followed by location specific surveys.

PRESENT METHODOLOGY FOR GROUNDWATER ASSESSMENT

The guidelines for evaluation of groundwater resources were prepared and circulated for the first time in 1972 by the Government of India. For the alluvial areas they suggested that recharge (Rp) due to rainfall should be calculated by using the formula:

Rp = 2.0 (R-15) 2/5

Where R = annual rainfall in inches.

The formula is applicable to areas having rainfall over 15 inches.

Since hard-rock areas have wide variations in the local conditions, it was suggested to adopt a location specific approach. After subtracting subsurface runoff losses, which are likely to be substantial in the hard-rock areas, it was suggested that evaluations consider the net contribution to groundwater recharge as 7.5% of the average rainfall. This could be adjusted depending upon the local topographical, geological and climatic factors. Norms were also suggested for other factors related to recharge and draft of groundwater.

Following this, in 1978, the Agricultural Refinance and Development Corporation (ARDC) now National Bank of Agriculture and Rural Development (NABARD) constituted a Committee called "The Groundwater Overexploitation Committee" (ARDC 1979). It reviewed the existing norms and the scientific work done since then and suggested the following new norms:

A. Recharge from Rainfall

i)	Alluvial Areas:	
	Sandy areas	20 to 25% of Normal Rainfall
	Areas with high clay soils	15 TO 20% of Normal Rainfall
ii)	Hard-rock Areas:	10 to 15% of Normal Rainfall

In addition to the above norms, the committee suggested that, if on the basis of field studies, the State Groundwater Organisations (SGO) finds that the percentage of rainfall infiltration is less than the above figures in either alluvial or hard-rock areas then the actually observed values should be adopted. Norms were also recommended for recharge from other sources and draft from groundwater structures. It was further suggested that given sufficient data, if groundwater development in a block/taluka is over 60% of the recoverable recharge, the groundwater should be evaluated by the water table fluctuations and specific yield approach.

Another committee was constituted by Ministry of Irrigation, Government of India in 1982 to refine groundwater assessment methodologies. The main recommendation of this committee was that for estimating the groundwater recharge, water level fluctuation and specific yield approach should be applied as far as possible. The committee also prescribed other norms which were more liberal than the 1979 ones. The unit for assessment was a community development block and these were to be categorised as dark, gray, and white depending on the level of groundwater development (85%, 65% and less than 65% respectively) 5 years following the assessment. Detailed micro level studies were to be done in dark blocks before any loan sanction by NABARD. However, in practice, the state government groundwater organisations, instead of taking up such studies, preferred the block to remain dark, or tried to revise the norms in a way so as to bring back the block in gray or white category so that loans from groundwater development could be sanctioned by banks. In Uttar Pradesh, for example, there were 141 dark blocks in 1984. This dropped to 17 in Jan 1990, in spite of the fact that during the six year period groundwater draft had increased tremendously (see Table 5).

Table 5. Categorisation of Blocks in U.P. According to G.W. Development in the Period 1980-90

	Year	Total No. of Blocks Assessed	Categorisation of Blocks		
			Dark	Gray	White
1	Jan 1980	876	37	193	646
2	Nov 1981	876	28	199	649
3	May 1983	876	51	184	641
4	Apr 1984	876	141	226	509
5	Mar 1985	876	53	112	711
6	Dec 1985	895	10	116	769
7	Jun 1986	895	26	117	752
8	Dec 1987	895	19	154	722
9	Jun 1989	895	17	85	793
10	Jan 1990	895	17	67	801

Source: NABARD

In fact the preparation of norms and standard format for estimating the groundwater balance by NABARD has been reduced to a paper exercise. No serious efforts have been made by the Central Groundwater Board (C.G.W.B.) or State Groundwater Organisations (S.G.O.) for scientific assessment based on local conditions. The job of calculating the actual draft from existing groundwater structures has been completely neglected. In no state have observations been made of the actual hours of pumping, discharge, cropping pattern of any privately owned well/tubewells.

Furthermore, recommendations of the Groundwater Estimate Committee 1984 indicate that groundwater potential could be estimated completely based on ad hoc norms and values except for groundwater table observation. Even with regard to the water table fluctuations and observations, there are the following lacuna:

i) Water table observations are usually made on derelict dug water wells and those used for drinking water which are located adjacent to paved roads. Hydrogeologically this approach is incorrect. Observation wells should be uniformly located in the aquifer area and should have good hydraulic connections with it. Installation of piezometres is really needed but has not been done by CGWB or CGOs so far except in some project areas.

ii) Water table observation in the states is mostly done by daily wage workers and so the reliability is doubtful.

iii) Specific yield value in zone of water table fluctuation is seldom worked out by performing pump tests on shallow tubewells. It is taken from the ad hoc norms given by the Estimates Committee.

iv) Little or no research work has been done by CGWB/SGOs to refine the following parameters:

   a) Rainfall infiltration rate in various types, of soils
   b) Rates of deep percolation
   c) Consumptive use by deep rooted trees
   d) Contribution to groundwater recharge from seepage in canals/tanks/reservoirs
   e) Movement of groundwater in hard-rock areas is extremely complex due to diversity in the conditions of groundwater occurrence within a definite groundwater basin. The difficulties which crop up in direct or indirect quantitative estimation of recharge in hard-rock terrain are primarily inherent in the geologic environment (Niyogi 1971). As such much more research work needs to be done on groundwater hydrology in hard-rock areas.

SUGGESTED METHODOLOGY FOR GROUNDWATER ASSESSMENT

In view of the shortcomings listed above for the present groundwater assessment methodology, the following suggestions are made :

1. The unit area for groundwater potential assessment should be a basin or sub-basin and not administrative boundaries like district, taluka/block or panchayat.

2. For each basin/sub-basin complete water budgeting should be done by using the following equation (Todd 1959)

   Surface inflow + subsurface inflow + precipitation + imported water + decrease in surface storage + decrease in groundwater storage = surface outflow + subsurface outflow + consumptive use + exported water + increase in surface storage + increase in groundwater storage

   In this form the equation includes all water - surface and subsurface entering and leaving a basin.

3. The above work should be taken up by S.G.O.s and C.G.W.B. immediately.

4. NABARD should dispense with sanctioning loan schemes on the basis of blockwise groundwater balances worked out following the Groundwater Estimates Committee norms. Instead, the criteria for sanction should be groundwater table trends. Schemes should be sanctioned based on the following data :

   i) Yield of existing groundwater structures, their annual running hours, and the crops irrigated.
   ii) Strata charts for existing wells/tubewells in the area.
   iii) Ten years plotting of water table in existing wells.
   iv) Existing minimum spacing between two structures running simultaneously without interferences.
   v) Annual rainfall for the last 10 years.

5. The unit area for scheme should be sub-basin/panchayat.

6. Number of additional structure possible should be decided on the basis of minimum spacing criteria, subject to the conditions that 10 years plot of water table data does not show a definite declining trend.

7. When the area falls in command of running canal system which runs more than 100 days in a year, the sanction of additional groundwater structures should be done liberally subject to aquifer availability.

8. Farmers of the area should be fully involved in the collection of basic data as listed above. Educated panchayat members can be trained for collection and compilation of this data. Explanatory guidelines and pro forma for this work can be printed in the local language. Panchayat should make it obligatory on farmers that wherever they engage any drilling agency, they must insist on strata charts.

9. Panchayat office buildings should have a rain gauge for recording daily rainfall. The rain gauge, tape, stop watch and other necessary equipment for measurement/observations should be supplied to panchayats by S.G.O.s.

CONCLUSION

The present estimates of groundwater potential and categorisation of blocks into dark, grey and white category are far from reality and cannot be used as a basis for planning groundwater development. Accurate assessments of groundwater balance require basin/sub-basin evaluation of total water availability (both surface water and groundwater) based on observed values of the basic parametres. Actual siting of wells/borewells/tubewells in any area should be based on suitable aquifer availability, local knowledge of existing structures, and geomorphology and natural vegetation.

Availability of groundwater is a certainty in the command areas of surface water projects, because of heavy seepage from unlined canals. In other areas, groundwater extraction has to be limited to recharge from rainfall. In several such areas considerable decline of groundwater table has already taken place. Other areas may also come in this category if the basis of check continues to be dark, gray and white instead of long term behavioural trend of water table. Artificial recharge methods as given in books and recommended by SGO/ CGWB are generally impractical and costly. In such cases the surest way is to introduce surface water irrigation or undertake rainwater harvesting through construction of tanks, check dams and contour bunds.

In canal and tank command areas, farmers have already gone for conjunctive use of surfacewater and groundwater by constructing wells and tubewells where water scarcity exists. In other cases where plentiful canal/tank water is available, farmers do not feel inclined to go for groundwater on account of surface water being very inexpensive compared to groundwater. In addition, irregular power availability constrains groundwater development in many such areas. In such cases there is an urgent need to rationalise irrigation water rate structures backed by scientific conjunctive use planning by S.G.O.s and C.G.W.B. with farmers' participation. Farmers have to play a vital role and their cooperation has to be enlisted at every stage.

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SUSTAINABILITY OF GROUNDWATER FOR WATER SUPPLY: COMPETITION BETWEEN THE NEEDS FOR AGRICULTURE AND DRINKING WATER

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Abstract

The Netherlands government is assisting the Gujarat Water Supply and Sewerage Board (GWSSB) in rural water supply and sanitation schemes: two with their sources relying on ground water and one on surface water. The two schemes relying on groundwater resources provide water to approximately 270 villages with an estimated population of more than 300,000. Also, provision for cattle included.

The resources of both schemes encounter rapidly falling water tables (3 to 6 m/y) and decreasing quality (fluoride). The reason is overdevelopment of the aquifers, mainly for irrigation. Close monitoring of the water levels has been established. Several alternative resources have been investigated but can not counterbalance the ever increasing requirements for irrigation.

At local scale water use efficiency for irrigation will be introduced in the surroundings of the well field. In order not to lose the investments made in the distribution network for water supply, water will have to be brought in from a distance, and at high cost.

INTRODUCTION

The Netherlands government has been assisting the Gujarat Water Supply and Sewerage Board (GWSSB) since 1978 in three rural water supply and sanitation schemes: two with their sources relying on groundwater and one on surface water. The two schemes relying on groundwater resources provide water to approximately 270 villages with an estimated population of more than 3,00,000. The distribution of water is mainly through standposts and cattle trough. The provision is based on a minimum supply for population and cattle. In addition extensive programmes for socio-economic and health education activities have been developed. The programme is executed by the GWSSB and several NGOs. There is a review and support mission from the Netherlands twice a year.

Technically, the distribution network starts at a well field from where the water is conveyed through long pipelines under gravity. From the pipeline branches bring the water to clusters of villages. In the villages the water is delivered into a cistern from where it is distributed to standpost(s) and cattle trough(s). The length of the main line in such a scheme (often duplicated or even triplicated) is 80 to 100 km whereas the total length of pipelines is more than 500 km. All the water distributed is originating from the wellfield where it is pumped from different aquifers.

The resources of the two groundwater based schemes in Banaskantha and Mehsana districts encounter rapid falling water tables (3-6m/y) and deteriorating quality of the water (fluoride), threatening the sustainability of the drinking water supply in the region.

RESOURCES

The well field at Shihori supplies to the Santalpur scheme and the well field at Kamlivada to the Sami-Harij scheme. In Shihori detailed monitoring has been established since 1986. The well field in Kamilvada has been taken into exploitation in 1992. The hydrogeological conditions are more complex in this region. In addition, recharge of the aquifers has reduced by the construction of the Mukteswar dam upstream of the well field.

Both wells fields at Shihori and Kamilvada have a small production compared to the production from the many irrigation tubewells around these well fields. Therefore, the rapidly declining groundwater levels are due to the unlimited pumping for irrigation in the region.

The well fields are not immediately affected by declining water levels since well diametres allow for adjusted pumpsetting. However, in the long term, energy consumption will increase and the quality of the water will deteriorate. There is no way to stop the general decline in water unless pumping for irrigation can be reduced.

The quality of groundwater in the immediate region of the well field is reasonable except for locally elevated fluoride levels. However, in both well fields the quality of groundwater is deteriorating, probably caused by the declining groundwater levels. The Shihori well field has a better quality groundwater than the Kamilvada well field. Records of data on the latter, being taken into production only recently, are relatively short. The area east and south-east of Kamlivada is known for its deteriorated and rather saline groundwater. The development of the water quality in tubewells around the well field indicates that a further deterioration of the water quality in these tubewells of the well fields can be expected.

Monitoring of tubewells and construction and monitoring of piezometres on a regular basis appear to be very helpful in obtaining reliable hydrogeological and geochemical information. This information has already proven to give better and broader insight in subsurface processes and can be used in long term planning of suitability and availability of groundwater resources.

The predominant importance of groundwater abstractions for irrigation can be demonstrated by the information collected from the Shihori wellfield. The production from this well field (see Figure 1) has increased from around 6 mld to about 9 mld since 1989. The (near) static water levels (Figure 2) show however a continuous drop in all wells without a notable influence of the increased pumping rate. The period of measurements covers poor and good monsoon seasons. It can be seen that the levels rise remarkably after good rains but that the general tendency of decline restores rapidly after monsoon. So a good monsoon has only a temporary effect. In Figure 3 a momentary situation of the water table is given. There is no influence of the wellfield on the regional groundwater pattern to be seen. Figure 4 gives the fluoride levels.

Fig. 1 Shihori Well field Production

Fig-1

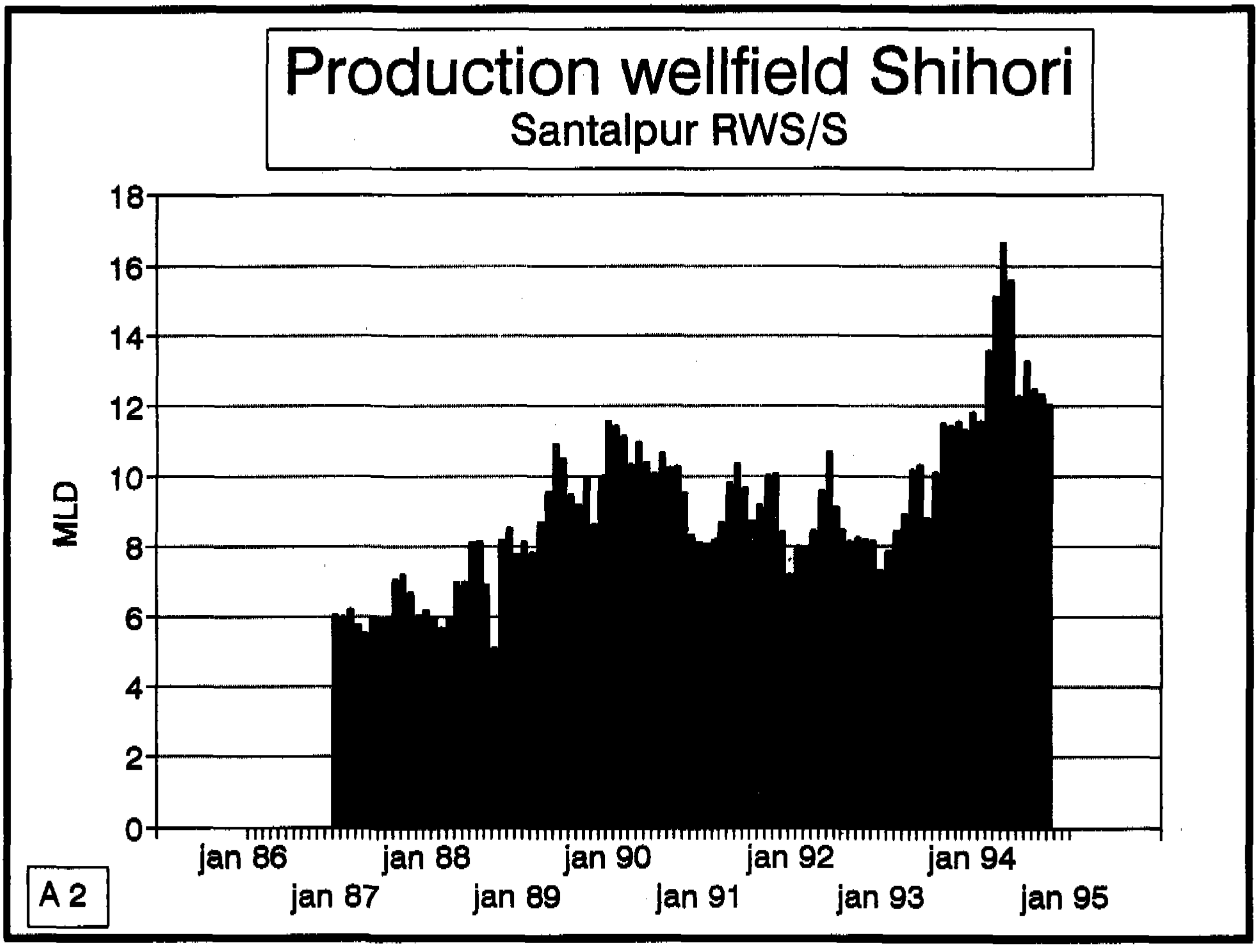


Fig. 2 Static Water Levels at Shihori

Fig-2

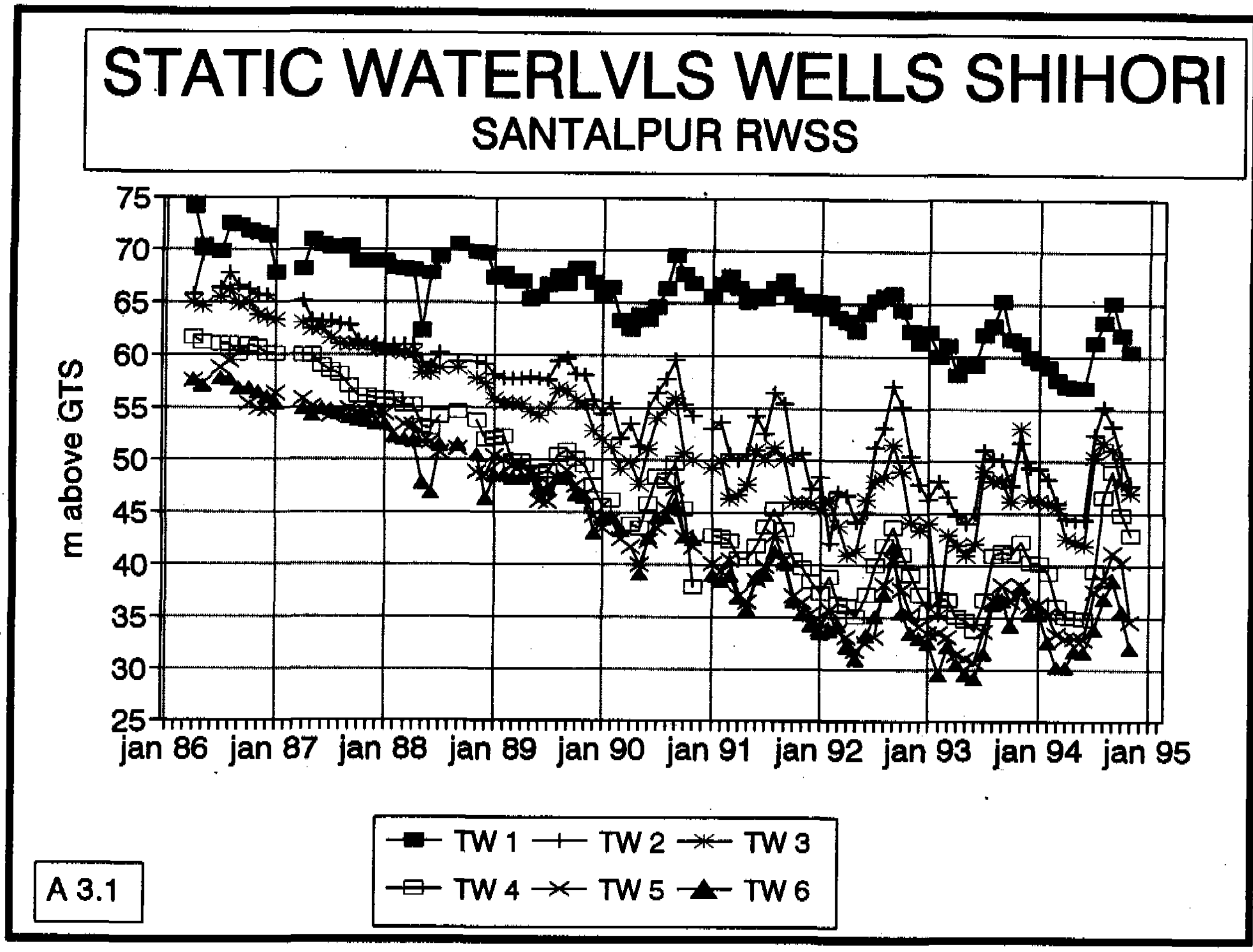


Fig-3

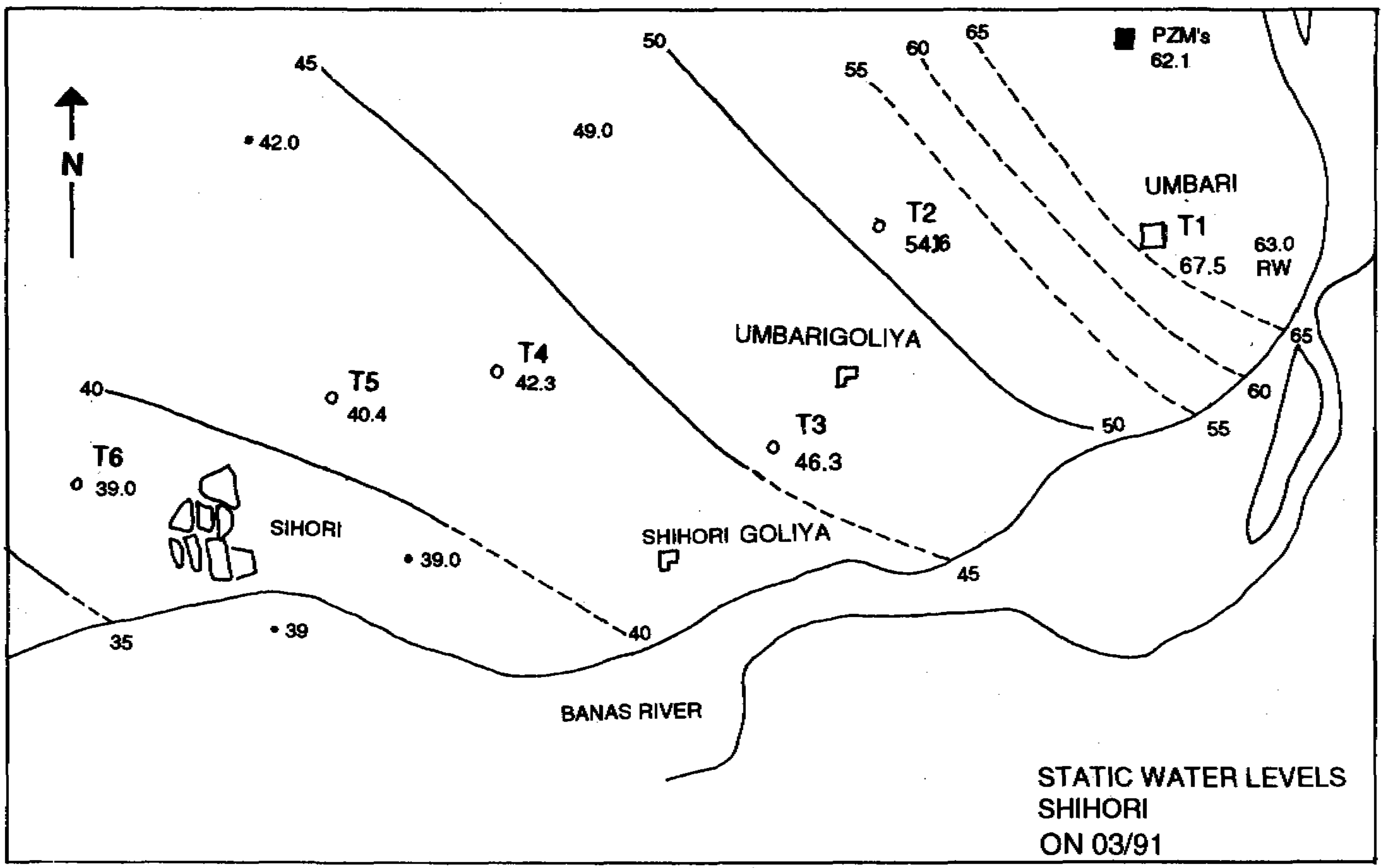
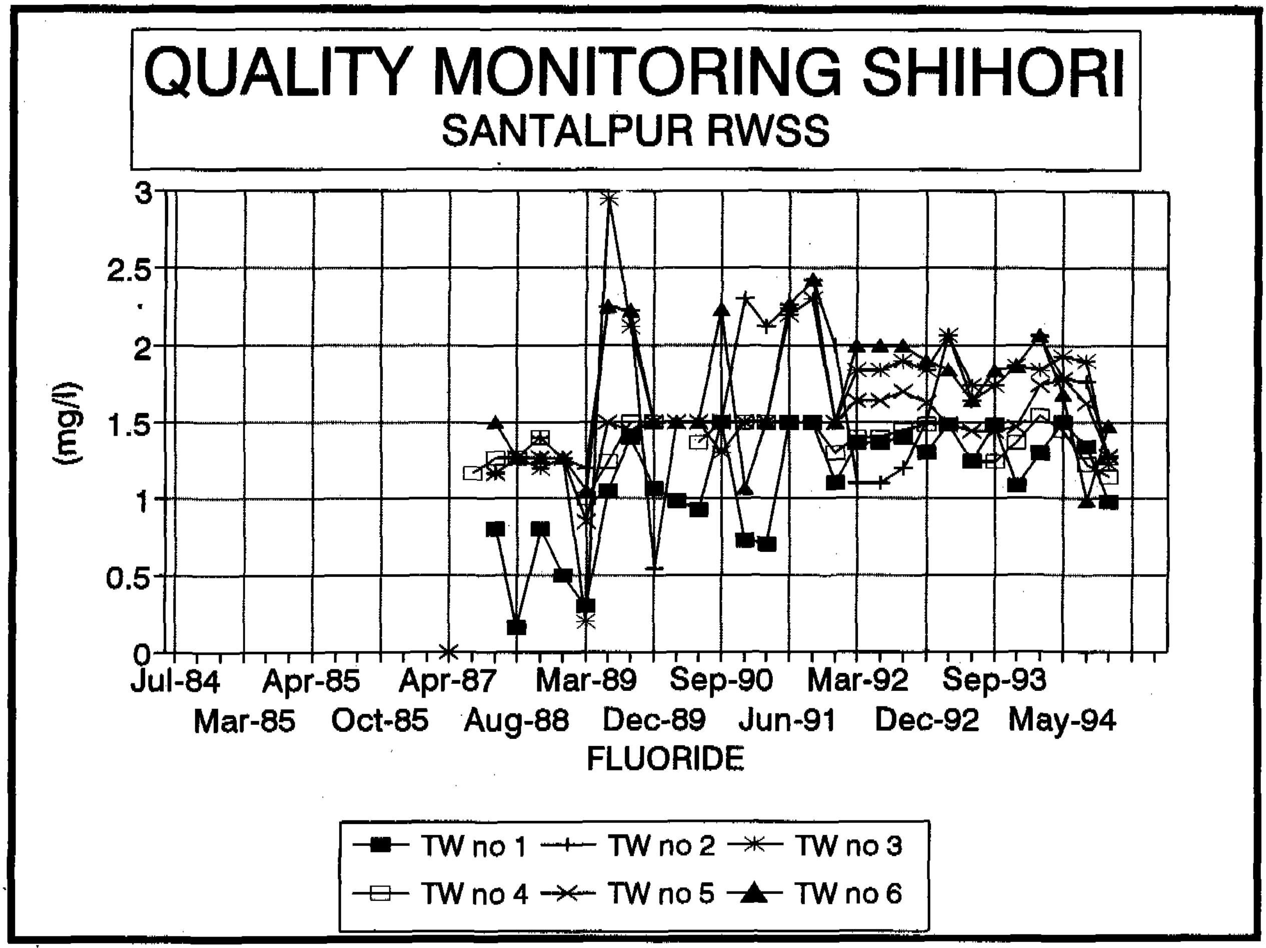


Fig. 3 Static Water Level Map in Shihori Well Field

Fig. 4 Fluoride Levels at Shihori

.Fig-4



In 1991 a survey was made of the existing wells for irrigation around the well field (radius 0.2 km). This survey has been repeated in 1992 and the results are given in Tables 1 and 2.

Table 1. Irrigation Wells Existing in 1991 within 0.2 km of Well Field

Sl. No.	Motor Capacity	No. of Pumps	Discharge	Pumping Hours	Total Discharge in l/s
1	25 HP	4	70,000	10	2,800,000
2	20 HP	6	60,000	10	3,600,000
3	15 HP	29	40,000	10	11,600,000
4	12.5 HP	4	35,000	10	1,400,000
5	10 HP	8	30,000	10	2,400,000

Table 2. Irrigation Wells Added between 1991 and 1992 within 0.2 km of Well Field

Sl.	Motor Capacity	No. of Pumps	Discharge	Pumping Hours	Total Discharge in litres
1	25 HP	4	70,000	10	2,800,000
2	20 HP	2	60,000	10	1,200,000
3	15 HP	2	40,000	10	800,000
4	10 HP	1	30,000	10	300,000

It was found that since 1991 within a radium two km, 9 more wells have been created increasing the capacity for irrigation by approximately 25%. Thus the abstractions for irrigation purpose still expand despite a legal ban on the creation of more tubewells.

LEGAL FRAMEWORK

The national water policy in Gujarat does give first priority to drinking over other uses. However the practical basis for policy implementation on legal grounds is weak.

By President's Act No. 3562818 assented on the 23rd December 1976, the Bombay Irrigation (Gujarat Amendment) Act, 1976, came into force.

In this Act it is stated that "where a holder of any agricultural land desires to construct therein any tubewell, artesian well or borewell, exceeding 45 metres in depth for extracting groundwater, he shall Mate an application to the Regional Canal Officer having jurisdiction for the grant of a license".

Holders of existing tubewells with depth in excess of 45 metres shall be licensed if they provide information in respect of the well. In fact the Act regulates the uncontrollable increase of tubewells and subsequent exploitation of the deeper aquifers for irrigation purposes.

The impact of the Act is practically zero. There is no effective control. Due to the overexploitation of groundwater for irrigation purposes the water tables are falling in the Saurashtra, Kutch and North Gujarat regions.

The reasons for defective control are likely due to the overestimation of the resources in the past, which is generally done in terms of irrigation potential. Apart from that, there is a lack of serious concern and so far an uninterested attitude among national and local authorities.

What is required is a more appropriate legal framework, supported by the authorities at all levels, and clear operational directives for the priority to be given to drinking water over other uses.

FUTURE DEVELOPMENTS

In Gujarat most catchments have been developed already to a large extent. A considerable part of the upstream catchments is however located in Rajasthan where catchments have been developed to a lesser extent. When these catchments will be developed in the future, less water will flow into Gujarat. At the same time the requirements in Gujarat will grow with increased population. Different options need to be explored at the same time:

a. Legal and operational framework with effective control. In order to achieve the optimum use of groundwater resources a consensus is required between the Ministries of Agriculture and Family Welfare. Operational guidelines should be worked out. Effective control has to be set up for long term sustainable development of the resources. This means less pumping for irrigation

b. Scarcity awareness, development of the resources and efficient use of water. The latter includes reduction of losses and spillage; efficient use of drinking water and water efficient agriculture practices and cultures.

c. Technical measure like water harvesting, import of water from a distance, desalinisation, etc. The technical measures are usually very expensive and offer only medium term solutions. For long term solutions priority has to be given to better management of the water resources.

Selected Titles on *Forestry* from VIKSAT

Publications

1. Trees and Plantation Techniques (G)
2. Nursery Techniques (G)
3. Fruit Nursery (G)
4. Grasses For Wasteland Development
5. Nursery and Plantation Calendar (G,E,H)
6. Byelaws of Tree Growers' Cooperative Society (G)
7. Development of People's Institutions for Management of Forests (E)
8. *Naseeb Nu Pandedu*- Manual on Timru leaves Collection (G)
9. Footprints in Forest Protection (E,G)

News letter on Natural Resource Management

NIYATI- Bi-monthly (G)

Video

1. *Ekta No Vagdo* (People's Forest)- 20 Min (G,E)
2. *Jaja Hath Raliyamana* (Joining Hands Together)- 20 Min (G,E)
3. Nursery: Planning & Management - 20 Min (G)
4. *Sapnana Vavetar* (Microplanning Processes) 20 Min (E,H,G)

Slide Show

1. Nursery: Planning & Management- 55 Slides (G)
2. Soil-Water Conservation Techniques- 55 Slides (G)
3. Wastelands: Causes & Effects - 77 Slides (G)

G = Gujarati E = English H = Hindi

VIKSAT

VIKSAT was set up in the year 1977 as an activity of the Nehru Foundation for Development (NFD), a registered public charitable trust, founded by Dr. Vikram A. Sarabhai. VIKSAT's activities are governed by a Council of Management consisting of eminent persons in the field of natural resource management.

MISSION

VIKSAT aims, through interaction with Government Organisations, NGOs and People's Institutions, at promoting and strengthening People's Institutions with active involvement of men and women from all sections of the community for equitable, gender sensitive and sustainable development and management of natural resources.

ACTIVITIES

VIKSAT's major programme areas are Joint Forest Management (JFM) and Participatory Groundwater Management. At the grassroots level, VIKSAT works with the village communities in its field projects in Bhiloda taluka of Sabarkantha district and Kheralu taluka of Mehsana District in Gujarat.

The role of VIKSAT in the field programmes is to facilitate emergence of People's Institutions, build their technical and organisational capacities through training, enable their increased access to government schemes and assist them in implementing resource management activities. The focus of field programmes is to expand the scope of participatory natural resource management both in magnitude and quality.

VIKSAT also performs the role of a Resource Centre. VIKSAT provides support to NGOs, Government Organisations and People's Institutions working in the state through newsletters, publications and audio-visuals for information dissemination, training for capacity building and process documentation for experience sharing.

VIKSAT publishes a bimonthly newsletter NIYATI in Gujarati for wider dissemination of knowledge about issues, concepts and practices in environment and natural resource management. In 1995, VIKSAT initiated SAKSHAM - a network of People's Institutions and NGO's working in the forestry sector in the state - with a view to promote and strengthen People's Institutions.

VIKSAT is the Regional Resource Agency, appointed by the Ministry of Environment and Forests, for facilitating the National Environment Awareness Campaign (NEA the state of Gujarat since 1988.

Selected Titles on *Forestry* from VIKSAT

Publications

1. Trees and Plantation Techniques (G)
2. Nursery Techniques (G)
3. Fruit Nursery (G)
4. Grasses For Wasteland Development
5. Nursery and Plantation Calendar (G,E,H)
6. Byelaws of Tree Growers' Cooperative Society (G)
7. Development of People's Institutions for Management of Forests (E)
8. *Naseeb Nu Pandedu*- Manual on Timru leaves Collection (G)
9. Footprints in Forest Protection (E,G)

News letter on Natural Resource Management

NIYATI- Bi-monthly (G)

Video

1. *Ekta No Vagdo* (People's Forest)- 20 Min (G,E)
2. *Jaja Hath Raliyamana* (Joining Hands Together)- 20 Min (G,E)
3. Nursery: Planning & Management - 20 Min (G)
4. *Sapnana Vavetar* (Microplanning Processes) 20 Min (E,H,G)

Slide Show

1. Nursery: Planning & Management- 55 Slides (G)
2. Soil-Water Conservation Techniques- 55 Slides (G)
3. Wastelands: Causes & Effects - 77 Slides (G)

G = Gujarati E = English H = Hindi

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