Working Paper No. 92
RULNR Working Paper No. 7
December, 2010

Groundwater: Development, Degradation and Management (A Study of Andhra Pradesh)

M. Srinivasa Reddy
V. Ratna Reddy

RULNR
RESEARCH UNIT FOR LIVELIHOODS AND NATURAL RESOURCES
(Supported by Jamsetji Tata Trust)
CENTRE FOR ECONOMIC AND SOCIAL STUDIES
Begumpet, Hyderabad-500016

Acknowledgements

This is a collaborative study between Research Unit for Livelihoods and Natural Resources (RULNR), in Centre for Economic and Social Studies (CESS), Hyderabad and Livelihoods and Natural Resources Management Institute (LNRMI), Hyderabad. Thanks are due to the Department of Ground Water, Government of Andhra Pradesh for providing all the secondary data, especially to the Special Commissioner Irrigation and Command Area Development Dr.A.K.Jain, Director Mr. B.M. Murali Krishna Rao and Assistant Director, Mr. N. Srinivasulu. Thanks are also due to Dr. Charles Batchelor, Dr. R. S. Deshpande and Dr.M.S. Rammohan Rao for useful discussions on the subject. We are also thankful to Professor M. Gopinath Reddy and Dr. Jyothis Sathyapalan and other colleagues of RULNR and CESS for their support and encouragement at various levels of the study. Thanks are due to Mr. Sanjit Kumar Rout for analysing the data, especially the regression analysis. Thanks are also extended to Dr.M. Venkataswamy and Dr. N. Jayakumar for their help and encouragement.

Groundwater: Development, Degradation and Management (A Study of Andhra Pradesh)

M. Srinivasa Reddy♦ , V. Ratna Reddy♦ ♦

Abstract

Hydrological knowledge or information has been mostly confined to the domain of scientific community, while the communities that actually interact with the hydrological aspects such as groundwater and surface water on a day-to-day basis are hardly aware of the information that could critically influence their livelihoods. From the perspective of the communities, information pertaining to groundwater aquifer characters, potential to provide the water resource, and surface groundwater interactions in varying geo-hydrological conditions are important. The public relevance of the resources and their linkages with ecological systems gives rise to externalities that could be pervasive. In a number of countries, especially the developing countries, groundwater is the single largest source of drinking as well as irrigation water. In the absence of scientific information with the communities, extraction of groundwater resources for productive purposes has become a risky venture leading to adverse impacts on livelihoods. The externalities associated with over exploitation of groundwater resources and the resulting widespread failure of wells is identified as one of the main reasons for pushing farmers in to debt trap and the resultant widespread farmer suicides in India. The negative externalities are also increasingly becoming severe in the context of climate variability.

This study attempts to highlight the importance of hydrological information to the user communities from a socio-economic perspective. It shows, based on the evidence, how groundwater is depleting along with increasing dependence over the years across the regions of Andhra Pradesh. It is argued that the negative externalities could be mitigated to a large extent with proper dissemination of information among the communities. In order to make the hydrological information relevant and useful for the

---

♦ Assistant Professor, Research Unit for Livelihoods and Natural Resources (RULNR),Centre for Economic and Social Studies (CESS), N.O.Campus, Begumpet, Hyderabad- 16.email: sreenivasdrreddy@yahoo.com

♦ ♦ Director, Livelihoods and Natural Resources Management Institute (LNRMI), Sarada Nagar, Hyderabad- 67, email:vratnareddy@lnrmi@ac.in

communities, it needs to be made user friendly and customised for the specific needs of the users. This must be fostered through policy support that paves the way for treating the resources as a common pool resource instead of allowing it to be exploited like a private resource. That is, groundwater resources ought to be brought under the management regime with the help of policy and governance structures.

Keywords: Groundwater, Surface water, Hydrology, Socio-economic, Environmental, Externalities, Developing Countries, India.

I Background

Groundwater management is the most challenging part of water management. Hitherto, groundwater policies were in the lines of encouraging over exploitation. These policies are in the nature of providing incentives for groundwater development such as subsidised credit, power, etc. While these policies helped in promoting groundwater development in the regions where groundwater development was below potential, they have led to over exploitation of the resource in fragile resource regions. The inter-connectedness of aquifers and the linkages between surface and groundwater have far-reaching environmental impacts. If the existing models are accurate, degradation of aquifers could adversely affect stream flows and water availability of downstream water users. As a result of degradation, majority of the resource-poor farmers have lost or are losing access to water, as the water tables go down. Even when they own bore wells, they cannot compete with the resource-rich farmers in deepening their wells (Reddy, 2005). That is, the poor are denied their rightful share in the Common Pool Resources (CPR's). As groundwater is the single largest source of irrigation and domestic water supply in a number of regions, its governance assumes importance and urgency.

In India the so-called water reforms have been in the lines of regulation rather than designing innovative policies that would integrate communities and institutional dimensions of resource management. Sustainable management of groundwater resources is crucial for ensuring long-term livelihood for farmers dependent upon it. In the absence of institutions that mitigate the tendency to over exploit CPRs, a rural agrarian system will be pushed towards extinction, especially when climate change-induced prolonged drought situations manifest with a higher frequency in the future. Farming communities are perceptive about the fact that improved availability of water for irrigation significantly enhances livelihood security. Moreover, the poverty alleviation goals necessitate a focus on the specific needs of the poor, especially the women and the landless and land-poor families. The issue of how to secure the rights and entitlements to water for the poor people needs to be addressed on a priority. Though there are regulations on groundwater exploitation, they are inadequate and ineffective in the absence of awareness and involvement of the user communities.

It is argued that the scientific knowledge should be shared with the farmers because of the simple reason that the sustainability of the resource lies in their hands (FAO, 2008). But the problem is with availability of accurate and reliable data. The available data is very sparse with low credibility due to the non-representativeness of the data. While farmers require at the village (micro-watershed of about 500 hectares) level, the available data in India is based on an observation well and a rain gauge station for every 25 sq km. One of the ways towards better and sustainable groundwater management is through improving the awareness among communities and building their capacity to measure and monitor groundwater levels on a seasonal basis.

II. Objectives and Setting

This study is an attempt to examine the dynamics of groundwater development over time and across regions, and highlight the importance of reliable information at an appropriate scale. The study also focuses on the importance of the involvement of local communities in generating such information and managing groundwater with appropriate capacities to measure and monitor the resource. It is argued, based on the evidence, that farmers are capable of understanding and learning the technical skills of hydrological monitoring. The basic idea is how to demystify science and make it accessible and user friendly to the communities. Specific objectives include: a) to examine the spatio-temporal variations in groundwater development in Andhra Pradesh (AP); b) to discuss the relevance of the existing information to the user or farming communities; and c) to explore the possibilities for generating reliable and useful information based on the existing experience at the ground level.

The study is based on the evidence from AP, which is among the states where groundwater is the single largest source of irrigation as well as drinking water. Besides, the state is severely affected by groundwater depletion, which is a cause of concern in terms of resource sustainability in general and groundwater and energy resources in specific. Management strategies can be planned only when the resource status/potential is known and the constraints are identified. Analysis of the trends in groundwater development and the examination of categorical shifts are considered as major steps towards formulating policies and programmes that aim to increase equity and enhance the sustainability of groundwater resources. Thus, the study is expected to help frame future policy that will facilitate and promote efficient and equitable groundwater management. Uneven distribution of groundwater in AP severely affects some regions, especially the drought and desert prone (DPAP and DDP) areas. These areas are characterized by large human and cattle populations which are continuously putting heavy pressure on the already fragile natural resource base for food, fodder and fuel. Any analysis which attempts to study the overall groundwater development in AP should consider these regional disparities.

The State of AP, consisting of an area of 2.75 lakh sq km, is endowed with a variety of physiographic features ranging from hills and undulating plains to a coastal deltaic environment. The state has three major river basins - Godavari, Krishna and Pennar. The entire state falls under the semi-arid region of Peninsular India and is characterized by hot summers and cold winters. Geomorphologically, the state can be categorized into pedi-plains, coastal alluvial plains and hill ranges (Figure 1 in Annexure). Major constraints are imposed by the spatio-temporal variations in water availability, though in aggregate terms, the water is sufficient to meet current demands in all but the driest years (FAO, 2004). The state receives an annual rainfall of 940 mm on an average, with wide variations among the districts. It ranges from 1200 mm in Srikakulam District to about 550 mm in Anantapur District. The majority of the rainfall (66%) is received from the south-west monsoon during June-September, while the north-east monsoon (October-December) contributes about 25% of the rainfall. Based on the rainfall and crops that could be grown, the state is divided into nine agro-climatic zones - high altitude and tribal zone, Krishna Zone, Godavari Zone, North Coastal Zone, Northern Telangana Zone, Central Telangana Zone, scarce rainfall zone, Southern Telangana Zone and Southern Zone (Figure 2 in Annexure).

The State of AP is underlain by rock types ranging from Archaean to recent alluvium with varied texture and structures. Nearly 85% of the state, i.e., about 2.33 lakh sq km, is underlain by hard rock's - igneous, volcanic and metamorphic rocks, mainly granites, gneisses and khondalites in the Eastern Ghats, Cuddapah (middle upper Protozoic), Kurnool and Deccan traps (Eocene). The remaining 15% of the area, i.e., 0.42 lakh sq km is underlain by soft rocks - tertiary and Gondwana sandstones & shales and alluvium of recent age. Dolerite dykes, quartz reefs, feldspathic and pegmatite veins extending from a few meters to a few kilometers cut across the country rocks at many places. The dolerite dykes have been emplaced along major prominent fractures. The vertical joints in granites are also aligned to the major direction of fractures/lineaments. Fluorite and apatite rocks contain fluoride-bearing minerals and are the main source of fluoride in groundwater (Figure 3 in Annexure).

Soils play an important role in improving groundwater recharge. The soils of the state are broadly classified into red, black and alluvial. Red sandy soils cover the largest area in the state (67%) and occur widely in the Telangana and Rayalaseema regions. The black soils are in general transported by rivers. The deltaic alluvial soils, coastal alluvial soils and coastal sandy soils are formed by the riverine system. Changes in land use can have significant effects on infiltration rates through the soil surface on water retention capability of soils and on sub-surface transmissibility (Swallow *et al.*, 2001).

The state's total water resources, both ground and surface water are estimated to be about 108.15 bcm (3820 tmc), out of which about 62.29 bcm (2200 tmc) is currently being utilized for drinking, agriculture, industry and power generation purposes. The per capita annual water resources work out to be slightly more than 1400 cum, and the utilization is about 800 cum (AP Water Vision, 2004). Countries or regions are considered water stressed when the annual per capita availability is between 1000 and 2000 cum. With the availability below 1700 cum, a region is deemed 'water scarce' and with less than 1000 cum, it becomes 'severe'. The current percentage of withdrawal of available water in AP is 58%. As per UN indicator, if the percentage withdrawal is more than 40%, the country is considered as water scarce. The average per capita water availability in AP as against India between 1951 and 2001 and the requirement for the year 2050 reflect the water stress (Table 1). This calls for efforts towards efficient management supported by appropriate policy framework for appropriate water governance.

Table 1: Per Capita Availability of Water in AP Compared to India (in cum)

Year	India	Andhra Pradesh
1951	5000	3600
1991	2100	1600
2001	1750	1400
2050	1140	912

Source: GoAP (2003), Water Conservation Mission.

This study is organised into six sections. The following section provides an overview of groundwater situation covering spatio-temporal aspects. Factors influencing groundwater development are estimated in section four. The experience of farmers managed groundwater systems under the project titled Andhra Pradesh Farmers Managed Groundwater Systems (APFMGS) is presented in Section V. Finally, Section VI pulls together the arguments and calls for credible and reliable hydrological information at the habitation level.

III. Groundwater Development in AP: A Spatio-Temporal Analysis

A recent expert group report (GoI, 2007) indicated that groundwater resources in the country are under severe stress. In 2004, an alarming 28% of the blocks in the country were in the category of semi-critical, critical or over exploited, compared to only 7% in 1995. Given the fact that groundwater is irrigating about 70% of the cropped area and supplying 80% of domestic water, it is clear that the resource is approaching a flashpoint. The rate of extraction far exceeds the rate of replenishment in many blocks, leading to a progressive lowering of the water table. The report perceives shortcomings in the legislative actions, including slowing down of development by the permit system, difficulties in enforcing regulations, scope for corruption and depriving new water users of water allocation. Unfortunately, groundwater development is still treated as a supply side issue, without any concern for demand side aspects.

Estimates of groundwater in India

India with 2.4% of the world's total area has 16% of the world's population, but has only 4% of the total available fresh water. This clearly indicates the need for water resources development, conservation and their optimum use. At the aggregate level, India is not short of water. The water resources potential of the country has been assessed from time to time by different agencies (Table 2). It may be seen that since 1954, the estimates have stabilized and are within the proximity of the currently accepted estimate of 1869 billion cubic metres (bcm), which includes replenishable groundwater that gets charged on annual basis.

Table 2: Estimates of Water Resources of India

Agency	Estimate (in bcm)	% Deviation (from 1869 bcm)
First Irrigation Commission (1902-03)	1443	– 23
Dr. A.N. Khosla (1949)	1673	–10
Central Water & Power Commission (1954-66)	1881	+ 0.6
National Commission on Agriculture	1850	– 1
Central Water Commission (1988)	1880	+ 0.6
Central Water Commission (1993)	1869	–

Source: GoI (2007), Report of the Steering Committee on Water Resources for Eleventh Five Year Plan (2007-2012), Planning Commission, May.

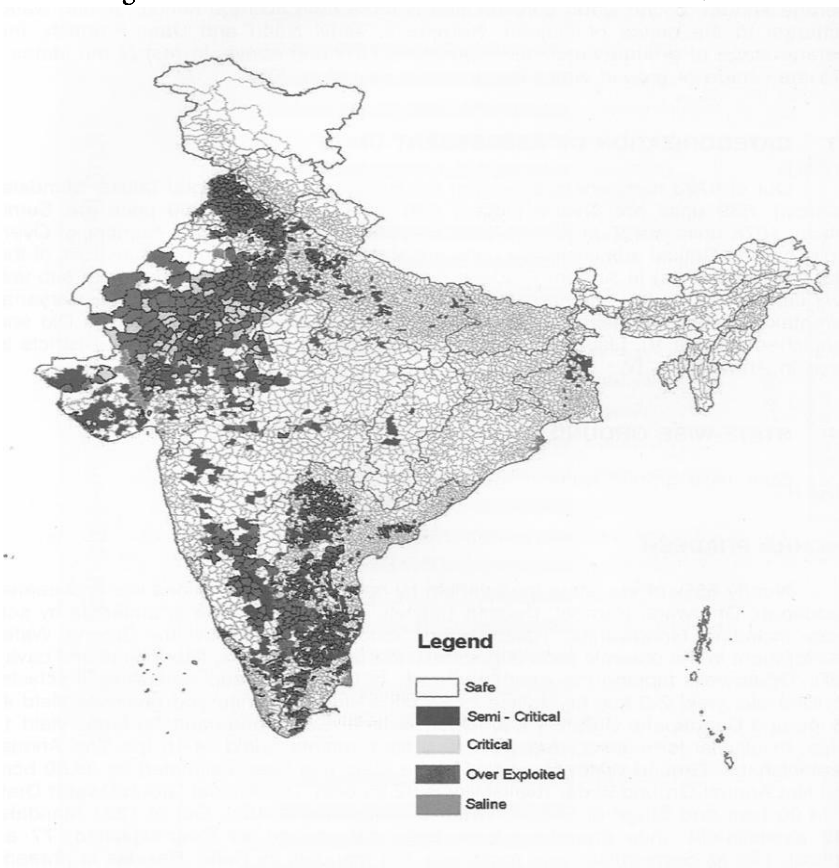
Within the limitations of physiographic conditions, socio-political environment, legal and constitutional constraints and the technology available at hand, the utilizable water resources of the country have been assessed at 1123 bcm, of which 690 bcm is from surface water and 433 bcm from groundwater sources (CWC-1993). Harnessing of 690 bcm of utilizable surface water is possible only if matching storages are built. Trans-basin transfer of water, if taken up to the full extent as proposed under the National Perspective Plan, would further increase the utilizable quantity by approximately 220 bcm. The irrigation potential of the country has been estimated at 139.9 million hectares (mha) without inter-basin sharing of water and 175 mha with inter-basin sharing. The requirement of water for various sectors has been assessed by the National Commission on Integrated Water Resources Development (NCIWRD) in the year 2000. This requirement is based on the assumption that the irrigation efficiency will increase to 60% from the present level of 35% to 40%. The Standing Committee of the Ministry of Water Resources (MoWR) also assesses it periodically (Table 3).

Table 3: Water Requirement for Various Sectors

Sector	Water Demand in km^3 (or bcm)					
	Standing Sub-Committee of MoWR			NCIWRD		
	2010	2025	2050	2010	2025	2050
Irrigation	688	910	1072	557	611	807
Drinking Water	56	73	102	43	62	111
Industry	12	23	63	37	67	81
Energy	5	15	130	19	33	70
Others	52	72	80	54	70	111
Total	**813**	**1093**	**1447**	**710**	**843**	**1180**

Source: GoI (2007), Report of the Steering Committee on Water Resources for Eleventh Five Year Plan (2007-2012), Planning Commission, May.

Categorization of Blocks/Mandals/Talukas as on March, 2004



Source: GoI (2006), Dynamic Groundwater Resources of India (as on March 2004), New Delhi

The annual replenishable groundwater resource for the entire country is 433 bcm. The overall contribution of rainfall to the country's annual replenishable groundwater resource is 67% and the share of other sources, including canal seepage, return flow from irrigation, seepage from water bodies and water conservation structures taken together is 33%. In the states of AP, Delhi, Haryana, Jammu & Kashmir, Jharkhand, Punjab, Tamil Nadu, Uttar Pradesh, Uttarakhand and the UT of Pondicherry, the contribution of other sources is more than the national average of 33%, mainly because of canal seepage and intensive irrigation. The southwest monsoon being the most prevalent contributor of rainfall in the country, about 73% of the country's annual replenishable groundwater recharge takes place during the kharif period of cultivation. Keeping 34 bcm as the allocation for natural discharge during the non-monsoon season, the net annual groundwater available for utilization in the entire country is about 399 bcm (Figure 4 in Annexure). The state-wise groundwater resources availability, utilization and categorization of over exploited and critical blocks are given in Table 4.

Status of groundwater in AP

In this sub-section, we examine the hydrological information that is available at the official level in AP. The official data sources are used to highlight the scale and intensity of the data generated on groundwater with the objective of identifying the gaps in information available at various levels. AP is one of the few states in India that compile detailed hydrological information. The source-wise composition of irrigation varies across different regions. While the rain-fed and drought-prone regions have experienced a shift towards groundwater irrigation, the endowed regions have continued to depend on surface water resources.

In AP, the first groundwater resource estimation was undertaken in the year 1985 and subsequently the same exercise was carried out five times till 2007. The Stage of Groundwater Development (SGD) in AP over the years is analysed on the basis of the groundwater resource estimation made by the State Groundwater Department (SGWD). These estimates are available at the district and regional level on the basis of command and non-command areas and also on the basis of drought prone (DPAP) and non-drought prone areas. The estimates are based on the readings from the Observation (OB) Wells or assessment units located at the *Taluk*/*Mandal*/Groundwater Basin/Watershed level (Table 5). The assessment unit is not same over the years. The number of assessment units was only 47 *Taluks* in 1985, though the coverage was expanded to all the *Mandals*, groundwater basins and Watersheds since 1993. These units are assumed to be valid for 26,586 villages spread over a geographical area of 0.28 million sq km in the state. Given the high spatial variations in the structure and quality of geo-hydrology and aquifers, the relevance of district or *Mandal* level data is quite dubious.

Table 4: State-wise Groundwater Resources' (in bcm) Availability, Utilization and Categorization of Assessment Units in India

State/ Union Territory	Annual Replenishable Ground water Resource	Natural Discharge during Non-Monsoon Season	Net Annual Ground water Availability	Annual Ground water Draft	Stage of Ground water Development (SGD) (%)	Categorization of Assessment areas (in Number)	
						Over Exploited	Critical
Andhra Pradesh	36.5	3.55	32.95	14.9	45	219	77
Arunachal Pradesh	2.56	0.26	2.3	0.0008	0.04	0	0
Assam	27.23	2.34	24.89	5.44	22	0	0
Bihar	29.19	1.77	27.42	10.77	39	0	0
Chhattisgarh	14.93	1.25	13.68	2.8	20	0	0
Delhi	0.3	0.02	0.28	0.48	170	7	0
Goa	0.28	0.02	0.27	0.07	27	0	0
Gujarat	15.81	0.79	15.02	11.49	76	31	12
Haryana	9.31	0.68	8.63	9.45	109	55	11
Himachal Pradesh	0.43	0.04	0.39	0.12	30	0	0
Jammu & Kashmir	2.7	0.27	2.43	0.33	14	0	0
Jharkhand	5.58	0.33	5.25	1.09	21	0	0
Karnataka	15.93	0.63	15.3	10.71	70	65	3
Kerala	6.84	0.61	6.23	2.92	47	5	15
Madhya Pradesh	37.19	1.86	35.33	17.12	48	24	5
Maharashtra	32.96	1.75	31.21	15.09	48	7	1
Manipur	0.38	0.04	0.34	0.002	0.65	0	0
Meghalaya	1.15	0.12	1.04	0.002	0.18	0	0
Mizoram	0.04	0.004	0.04	0.0004	0.9	0	0
Nagaland	0.36	0.04	0.32	0.009	3	0	0
Orissa	23.09	2.08	21.01	3.85	18	0	0
Punjab	23.78	2.33	21.44	31.16	145	103	5
Rajasthan	11.56	1.18	10.38	12.99	125	140	50
Sikkim	0.08	0	0.08	0.01	16	0	0
Tamil Nadu	23.07	2.31	20.76	17.65	85	142	33
Tripura	2.19	0.22	1.97	0.17	9	0	0
Uttar Pradesh	76.35	6.17	70.18	48.78	70	37	13
Uttaranchal	2.27	0.17	2.1	1.39	66	2	0
West Bengal	30.36	2.9	27.46	11.65	42	0	1
Total (States)	**432.42**	**33.73**	**398.7**	**230.44**	**58**	**837**	**226**
Union Territory (UT)							
Andaman & Nicobar	0.33	0.005	0.32	0.01	4	0	0
Chandigarh	0.023	0.02	0.02	0	0	0	0
Dadra & Nagar Haveli	0.063	0.003	0.06	0.009	14	0	0
Daman & Diu	0.009	0.0004	0.008	0.009	107	1	0
Lakshadweep	0.012	0.009	0.004	0.002	63	0	0
Puducherry	0.16	0.016	0.144	0.151	105	1	0
Total (UTs)	**0.597**	**0.036**	**0.556**	**0.181**	**33**	**2**	**0**
Grand Total	**433.02**	**33.77**	**399.25**	**230.62**	**58**	**839**	**226**

Source: GoI (2006), Central Ground Water Board, Dynamic ground water resources of India (as on March 2004), New Delhi.

Table 5: Details of Groundwater Assessment in Andhra Pradesh

Year of Assessment	Assessment Unit	No. of Units Assessed	Methodology	Actual Number
1985	Taluk	47	Water table fluctuation	308
1993	Mandal	1108	Water table fluctuation and rainfall infiltration	1124
2002	Groundwater Basin	1157	GEC 1997 methodology	1157
2004	Watershed	1229	GEC 1997 methodology	1229
2007	Watershed	1229	GEC 1997 methodology	1229

Source: GoAP, Groundwater Department, Groundwater Resource Estimated Reports.

The methodology adopted in Groundwater Estimation Committee (GEC) 1997 is reasonably valid in an approximately homogenous hydrologic terrain like alluvium. However, this may not be applicable for hard rock terrain where the hydro-geological conditions vary widely within small areas under the prevailing heterogeneous set up. Significantly, almost two-thirds of the area, including AP, is occupied by hard rock terrain (GoI, 2002). A committee appointed in 2001 has suggested modifications to the GEC-1997 methodology. The committee also left some important issues, such as norms of recharge components, return flow from irrigation, groundwater draft, base flow, spring discharge and specific yield, unresolved, and recommended for further studies and estimates. As a result, the methodology used for estimation is neither perfect nor appropriate for addressing the needs of the users, who need to know the actual groundwater available in their village on a season to season basis.

Groundwater resource of the state is estimated on a regular basis by the MoWR in close collaboration with the Ground Water Department of Government of AP. The administrative set up of the state was reconstituted into *Mandals* in 1985. Accordingly, groundwater resources in the state were estimated in 1995, following the norms recommended by the GEC 1984, taking 1993 as a base year. In 1997, a detailed methodology, along with a guide book giving all the computations needed for assessment was published by the GEC, a high power committee of the MoWR. This is often referred as the GEC 1997 methodology. In 2004, groundwater resource estimation using data of 2001 was completed, based on GEC 1997. Based on the recommendations of the "Groundwater Estimation Committee on Hard Rock Terrain", resource estimation was carried out again in 2005 with the base data of 2004. As per the methodology followed, the status of groundwater is given simply as a ratio of the utilization and recharge, which is called the SGD. It can also be called the stage of groundwater utilization for clarity.

The groundwater status was estimated for the year 1984-85 using the water table fluctuation method. The data of Central Groundwater Board (CGWB) observation well network, supplemented by SGWD observation well data, were used. All the calculations were made for the year 1984-85. The number of observation wells monitored in the year 1984-85 by CGWB and SGWD are 321 and 2698 respectively. The district-wise groundwater development in the state ranges between 6% and 59% and that of entire state is of the order of 28%. Recharge computations have been made separately for *ayacut* (command) and non-ayacut (non-command) areas. It is observed that most of the groundwater development is confined to the non-*ayacut* areas.

The total dynamic groundwater resources of AP were thus estimated at 25.3 bcm per annum as in 1984-85 and the utilizable groundwater resources for irrigation were worked out to be 25.30 bcm per annum (Table 6). The net annual groundwater draft in 1984-85 was 7.07 bcm. Thus, a balance of 18.23 bcm was available for future development. It is to be remembered that these estimates consider only the dynamic groundwater resources of water table aquifers.

Table 6: Estimates of Groundwater in Different Years of Assessment

(in bcm)

Year	Annual Availability	Annual Utilisation	Balance	S GD
1985	25.30	7.07	18.23	28
1993	35.29	10.13	25.16	29
2002	30.56	12.97	17.59	43
2004	32.76	14.86	17.90	45
2007	34.70	14.11	20.59	41

Note: Data compiled from Groundwater Resource Estimated Reports of different years, Ground Water Department, GoAP.

The net groundwater availability per annum, as per 1993 estimates, for the entire state was estimated to be about 35.3 bcm, which was 14.4% of the total quantity of water received through normal precipitation. From this, about 15%, i.e., 5.3 bcm was earmarked for drinking and other committed uses, leaving a balance of 30 bcm for irrigation. The net annual groundwater draft for irrigation was 7.09 bcm. The level of groundwater development across districts ranged between 7% and 43%, and for the state as a whole it was 25%. However, during this period, 5 *Mandal*s were categorised under dark and 60 *Mandal*s under semi-critical zones.

In 2002 the state was divided into 1193 assessment units, which include basins with defined hydrological boundaries in hard rock areas with areas ranging between 50 and 450 sq km and *Mandal*s (administrative blocks) in alluvial areas including 36 Saline

Mandals. Computations of net groundwater availability, its utilisation and availability for future use in all the assessment units for command, non-command and poor groundwater quality areas were made separately. The estimates showed the groundwater availability at 30 bcm, usage at 13 bcm and the balance at 17 bcm per annum.

The watershed boundaries were revised to 1229 during 2004. The estimates showed that groundwater availability was 32.8 bcm, usage was 14.9 bcm and the balance was 17.9 bcm per annum. These estimates included 1.3 bcm of net annual groundwater availability in poor quality and saline areas. The usage in saline areas was about 0.21 bcm. In comparison with 2002 estimates, there was a definite increase (by about 13%) in groundwater usage across sectors. This was corroborated by a steep decline in the mean water levels almost everywhere in the state. In many areas, water level stands in fractured formation, rather than in weathered formation, as shown by the network of existing Piezometers, and the drying up of traditional OB Wells. Groundwater development was at the highest level (45%) during 2004 due to the prevailing unprecedented drought conditions. The situation eased by 2007 with consecutive good monsoons resulting in a decline in the SGD (41%).

Groundwater Development in command and non-command Areas

In 2007, estimates were made separately for command and non-command areas using the GEC 1997 methodology, based on the data from Transmission Corporation of Andhra Pradesh Limited (APTRANSCO), Revenue Department and Irrigation Department. Corrections factors were applied based on the field observations. The total groundwater resources were estimated at 34.7 bcm (17.89 in non-command area + 16.81 in command area) and utilization was 14.11 bcm (10.53 in non-command area + 3.58 in command area), while the balance available resource was 20.59 bcm (7.36 in non-command area + 13.23 in command area). The average SGD for the entire state was 41%, of which 59% was in non-command areas while 21% was in command areas. The annual groundwater availability in AP during 2007 was 34.7 bcm. The overall draft in 2007 was around 14 bcm.

Table 7: Mandals and Villages under Different Categories (2007)

Category	Number of Watersheds	Number of *Mandals*	Number of Villages
Over Exploited	132	108	5096
Critical	89	60	1064
Semi-Critical	175	155	2632
Safe	833	782	17219

Source: GoAP, (2008), State Groundwater Department, Hyderabad.

The state has been categorized into four zones, viz., safe (<70%), semi-critical (70% to 90%), critical (90 to 100%) and over exploited (>100%), based on the percentage of groundwater exploitation. About 5096 villages, spread over 108 *Mandal*s and 132 watersheds, fall in the over exploited category consequent to the drying up of shallow aquifers (Table 7). Along with the overall groundwater development at the state and district level (Figure 1), the variation between command and non-command areas was also examined. The assessment shows that groundwater resources have reached a very critical stage in non-command areas (Table 8). All the areas of the state that are not served by canal command, including the areas in districts like West Godavari, Anantapur, etc., are showing very high usage of the available groundwater and this is reflected in the SGD, which exceeds 70% of the safe limit of exploitation. The total groundwater resources are estimated at 17.89 bcm in non-command areas and 16.81 bcm in command areas, while the utilization is 10.53 bcm in non-command areas and 3.58 bcm in command areas, and the balance available resource is 7.36 bcm in non-command areas and 13.23 bcm in command areas. The average SGD for the entire state is 41%, of which 59% is in non-command areas, while 21% is in command areas.

The estimates show that the overall SGD in AP has gone up from 28% in 1985 to 41% in 2007, except during the year 1993, when it declined to 24%. However, opposite trends are observed in the case of command and non-command areas between 1985 and 2002 - while the command areas have experienced an increasing trend, the non-command areas have experienced a declining trend. However, both command and non-command areas have shown an increasing trend between 2002 and 2004, which is due to the consecutive droughts during that period. Between 2004 and 2007, there was a decline in the level of development, reverting back to 2002 levels.

The overall SGD in Coastal Andhra was lesser when compared to the other two regions in all the groundwater resource estimated years. On the other hand, in Rayalaseema Region the SGD was higher compared to the other two regions during these years, except in 1985, when Telangana was marginally higher than this region. The trend with respect to the SGD in command areas was same in all the three regions during the estimated years 1985 to 2002, when it increased from 1985 to 1993 and then declined. After 2002, the trend was same in case of Coastal Andhra and Telangana Regions (increased between 2002 and 2004 and declined between 2004 and 2007) while the SGD in Rayalaseema showed an increasing trend during both the periods. The non-command areas of all the three regions exhibited a similar trend with respect to the overall SGD.

On the basis of overall SGD, districts were categorised as 'very high usage' (>70%), 'high usage' (>50% & <70%), 'moderate usage' (>30% & <50%) and 'low usage' (<30%)

Table 8: District/Region-wise Stage/Level of Groundwater Development in AP

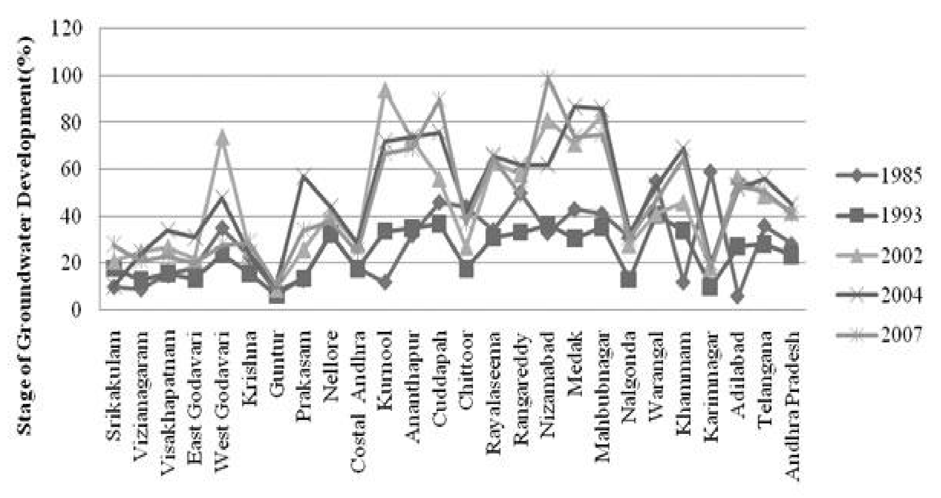
District/ Region	Stage/Level of Groundwater Development (%)														
	1985			1993			2002			2004			2007		
	C	NC	T	C	NC	T	C	NC	T	C	NC	T	C	NC	T
Srikakulam	1	37	10	18	17.9	18	15	23	21	10	10	10	19	35	28
Vizianagaram	2	20	9	13.2	13.1	13.1	15	30	25	19	28	24	16	24	21
Visakhapatnam	3	24	15	15.7	15.8	15.8	12	32	27	71	29	34	56	19	23
East Godavari	12	33	18	13.3	13.2	13.3	15	40	22	14	71	31	14	36	20
West Godavari	19	61	35	23.8	23.8	23.7	5	115	74	3	94	48	6	75	28
Krishna	9	56	23	15.9	16	15.9	18	35	26	14	53	24	19	70	29
Guntur	6	12	8	6.6	6.5	6.6	6	30	9	9	57	10	10	43	11
Prakasam	3	19	13	13.5	13.6	13.6	6	54	26	32	76	57	14	64	34
Nellore	13	54	32	32.5	32.5	32.5	33	49	41	36	53	44	29	53	38
Coastal Andhra	**8**	**34**	**18**	**16.5**	**19.6**	**17.8**	**13**	**49**	**28**	**16**	**53**	**29**	**15**	**47**	**25**
Kurnool	3	18	12	33.6	33.7	33.7	13	36	27	NA	72	72	0	67	67
Anantapur	10	41	32	35	35.1	35	35	80	73	43	82	74	27	87	69
Cuddapah	15	58	46	36.7	36.8	36.9	13	64	56	30	97	76	58	103	90
Chittoor	8	88	44	17.6	17.5	17.6	NA	94	94	21	59	42	30	48	37
Rayalaseema	**8**	**51**	**34**	**29.1**	**31.6**	**31.1**	**17**	**72**	**63**	**28**	**78**	**66**	**36**	**76**	**65**
Ranga Reddy	32	52	50	33.2	33.3	33.3	20	60	58	34	73	62	15	61	49
Nizamabad	5	90	33	36.6	36.5	36.4	NA	81	81	NA	73	62	0	99	99
Medak	9	63	43	30.7	30.8	30.8	NA	71	71	NA	87	87	0	74	74
Mahbubnagar	15	51	41	35.4	35.4	35.3	52	94	83	71	96	86	69	79	75
Nalgonda	5	55	31	13.2	13.2	13.2	32	27	28	33	33	33	28	32	31
Warangal	16	71	55	40.8	40.8	40.8	19	67	41	34	79	53	17	81	47
Khammam	5	14	12	33.8	33.9	33.9	25	53	46	56	80	69	59	70	65
Karimnagar	11	104	59	10.1	10.1	10.1	15	20	18	22	19	20	25	16	18
Adilabad	3	7	6	27.2	27.2	27.2	10	76	57	11	77	52	18	73	53
Telangana	**9**	**52**	**36**	**29.1**	**27.8**	**28.3**	**22**	**58**	**49**	**36**	**66**	**56**	**33**	**58**	**51**
AP State	**8**	**46**	**28**	**21.1**	**25.6**	**23.6**	**16**	**58**	**42**	**22**	**65**	**45**	**21**	**59**	**41**

Note: 1. Data compiled from Groundwater Resource Estimated Reports of different years, Groundwater Department, GoAP.

2. C= Command; NC= Non-Command; T=Total (both command and non-command taken together).

districts. As per the estimates of 1985, the SGD in coastal districts ranged from 8% (Guntur) to 74% (West Godavari). The three districts of Coastal Andhra (Srikakulam, Guntur and Krishna) show an increase in groundwater development compared to the other six districts in the region. In the Rayalaseema Region, the SGD ranged between 37% in Kurnool and 94% in Chittoor. While Anantapur District showed an increase in SGD, the other three districts, i.e., Kurnool, Cuddapah and Chittoor showed a decrease in SGD between the years. In the Telangana Region, the SGD varied from 6% in Adilabad to 99% in Ranga Reddy. While in Nalgonda District there was an

Figure 1: District-wise and Region-wise Level of Groundwater Develpopment % in A.P



increase in the use of groundwater and the SGD was raised from 52% to 53%, in all the other eight Telangana districts, the stage of development decreased - ranging from 2% in Khammam to 13% in Mahabubnagar, compared to the previous estimates. However, no district from any region came under the 'very high usage' category. Three of the districts in the Telangana Region (Ranga Reddy, Warangal and Karimnagar) came under the 'high usage' category, while two districts from Coastal Andhra (West Godavari and Nellore), three from Rayalaseema (Anantapur, Cuddapah and Chittoor) and four from Telangana (Nizamabad, Medak, Mahbubnagar and Nalgonda) were under the 'moderate usage' category; and seven Coastal Andhra districts (Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, Krishna, Guntur and Prakasam), one Rayalaseema district (Kurnool) and two Telangana districts (Khammam and Adilabad) were under the 'low usage' category.

Groundwater development estimates in 1993 showed that none of the districts from any region came under the 'very high' and 'high usage' category. Only one district from the Coastal Andhra (Nellore), three in Rayalaseema (Chittoor, Cuddapah and Anantapur) and six districts from the Telangana Region (Mahbubnagar, Ranga Reddy, Medak, Nizamabad, Karimnagar and Warangal) came under the 'moderate usage' category; while all the districts from Coastal Andhra, only one from Rayalaseema (Kurnool) and three from the Telangana Region (Adilabad, Khammam and Nalgonda) came under the 'low usage' category. During 2002, one district in Coastal Andhra (East Godavari), two in Rayalaseema (Chittoor and Cuddapah) and three in the Telangana Region (Ranga Reddy, Medak and Nizamabad) were found to be under the 'very high usage' category. The 'high usage' districts included one in Rayalaseema (Anantapur) and two in Telangana

(Mahbubnagar and Nalgonda). The 'moderate usage' category included one district in Coastal Andhra (Nellore) and two in Telangana (Karimnagar and Warangal), while seven districts in Coastal Andhra (Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, Krishna, Guntur and Prakasam), only one in Rayalaseema (Kurnool) and two in Telangana (Adilabad and Khammam) were under the 'safe/low usage' category.

The severe drought conditions preceding 2004 reflected in three districts in Telangana (Ranga Reddy/Hyderabad, Nizamabad and Medak) and three in Rayalaseema (Anantapur, Cuddapah and Chittoor), falling under the 'very high usage' category in 2004. One district in Coastal Andhra (Prakasam) and four in Telangana (Warangal, Mahbubnagar, Karimnagar and Nalgonda) came under the 'high usage category', while four districts in Coastal Andhra (Visakhapatnam, East Godavari, West Godavari and Nellore), one in Rayalaseema (Kurnool) and one in Telangana (Adilabad) were under the 'moderate usage' category. The 'safe/low usage' districts were Vizianagaram, Srikakulam, Krishna and Guntur from Coastal Andhra (four districts), and only one from Telangana (Khammam). The situation continued during 2007, when the number of 'very high usage' districts comprised three from Telangana (Ranga Reddy/Hyderabad, Nizamabad and Medak) and one from Rayalaseema (Anantapur). The 'high usage' districts included two districts from Rayalaseema (Cuddapah and Chittoor) and two from the Telangana Region (Warangal and Nalgonda). Two districts in Coastal Andhra (Nellore and Prakasam), one in Rayalaseema (Kurnool) and three in Telangana (Mahbubnagar, Karimnagar, Adilabad) came under the 'moderate usage' category. As many as seven districts from Coastal Andhra (Krishna, Srikakulam, West Godavari, Visakhapatnam, Vizianagaram, East Godavari and Guntur) and only one in Telangana (Khammam) were under the 'low/safe usage' category.

Groundwater Development in DPAP and Non-DPAP Districts

When the districts are categorised as DPAP and non-DPAP districts, the trends in groundwater development shows that the overall SGD in DPAP districts are higher than that of non-DPAP districts in all the assessment years except in 1985, when non-DPAP districts had a marginally higher level of groundwater development (Table 9). So far as command areas of DPAP and non-DPAP districts are concerned, except in 1985 and 2002, the command areas of DPAP districts had higher level of groundwater development than that of non-DPAP districts. The command areas of DPAP and non-DPAP districts exhibited a similar trend in all the years, i.e., increase in 1993 and 2004 and decline in 2002 and 2007, when compared to the respective previous years' estimates. As far as non-command areas of DPAP and non-DPAP districts are concerned, except in 2007, non-DPAP districts had higher level of groundwater development than the DPAP districts. Both command and non-command areas within the respective zones showed similar trends.

Table 9: Groundwater Estimates for DPAP and Non-DPAP Districts in AP

Scheme/ Year	Annual Groundwater Availability (mcm) (mcm)			Groundwater Utilization/Draft (mcm)			Groundwater Balance			SGD (%)		
DPAP	C	NC	Total	C	NC	Total	C	NC	Total	C	NC	Total
1985	4832	7774	12606	298	3047	3345	4534	4727	9261	6	39	27
1993	4562	9747	14307	1019	2461	3481	3542	7286	10823	22	25	24
2002	3423	12369	15792	437	7122	7559	2986	5247	8233	13	58	48
2004	3918	11473	15391	963	7302	8265	2955	4171	7126	25	64	54
2007	4760	11405	16165	1153	6795	7948	3607	4611	8218	24	60	49
Non-DPAP												
1985	7261	5435	12696	703	3025	3728	6558	2410	8968	10	56	29
1993	8415	7277	15690	1722	1895	3612	6693	5382	12078	20	26	23
2002	7825	6943	14768	1315	4101	5416	6510	2842	9352	17	59	37
2004	11048	6319	17367	2366	4223	6589	8682	2096	10778	21	67	38
2007	12054	6481	18535	2433	3731	6164	9621	2749	12370	20	58	33
AP												
1985	12093	13209	25303	1001	6073	7074	11092	7737	18229	8	46	28
1993	12975	17024	29997	2740	4356	7093	10235	12668	22904	21	26	24
2002	11248	19312	30560	1752	11223	12975	9496	8089	17585	16	58	42
2004	14966	17792	32758	3329	11525	14854	11637	6267	17904	22	65	45
2007	16814	17886	34700	3586	10526	14112	13229	7360	20588	21	59	41

Note: 1. Data compiled from Groundwater Resource Estimated Reports different years, Ground Water Department, GoAP.

2. C=Command (*ayacut*); NC=Non-Command (*non-ayacut*); Total=Overall (both command and non-command areas together).

Table 10: Districts by Category of Groundwater Development in AP

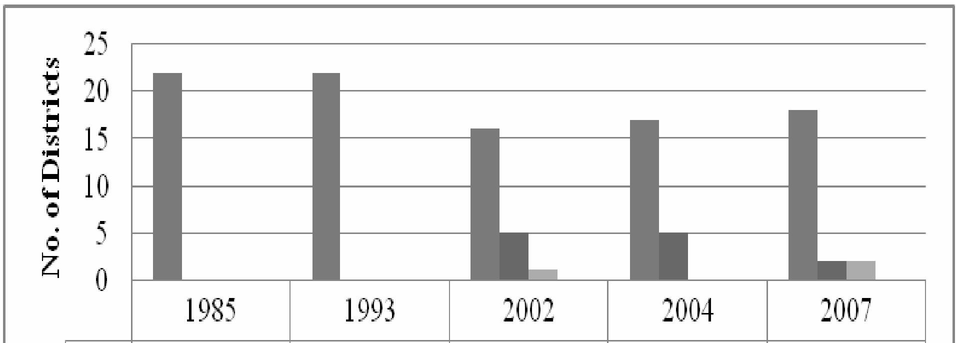
Category	No. of Districts falling under Different Categories												
	1985			1993	2002			2004			2007		
	C	NC	Overall	Overall	C	NC	Overall	C	NC	Overall	C	NC	Overall
Safe	22	18	22	22	18	15	16	17	9	17	19	12	18
Semi-Critical	0	1	0	0	0	4	5	2	10	5	0	8	2
Critical	0	2	0	0	0	2	1	0	3	0	0	1	2
Over Exploited	0	1	0	0	0	1	0	0	0	0	0	1	0
NA	1	1	1	1	5	1	1	4	1	1	4	1	1
Total	23	23	23	23	23	23	23	23	23	23	23	23	23

Note: 1. Data compiled from Groundwater Resource Estimated Reports different years, Ground Water Department, GoAP.
2. C=Command (ayacut); NC=Non-Command (non-ayacut); Total=Overall (both command and non-command areas together). NA= Not applicable or available.

Overall, the SGD of most districts was under the safe category in 1985 and 1993 (Table 10). In 1985, while all the command areas fell under the safe category, one was under semi-critical, two were under critical and one was under over exploited category. However, the situation changed after 1993. As far as the overall groundwater development was concerned, some districts which were under safe category during earlier years slipped to semi-critical (West Godavari, Cuddapah, Ranga Reddy, Medak and Nizamabad) and critical stages (Chittoor) in 2002. In the same year, the command areas of 18 districts were under safe category, whereas non-command areas of 15 districts were under safe, four were under semi-critical, two were under critical and one was under over exploited category, thus indicating the deteriorating situation in the non-command areas. In 2004, the overall groundwater development had pushed five districts into the semi-critical category (Chittoor, Cuddapah, Kurnool, Medak and Nizamabad).

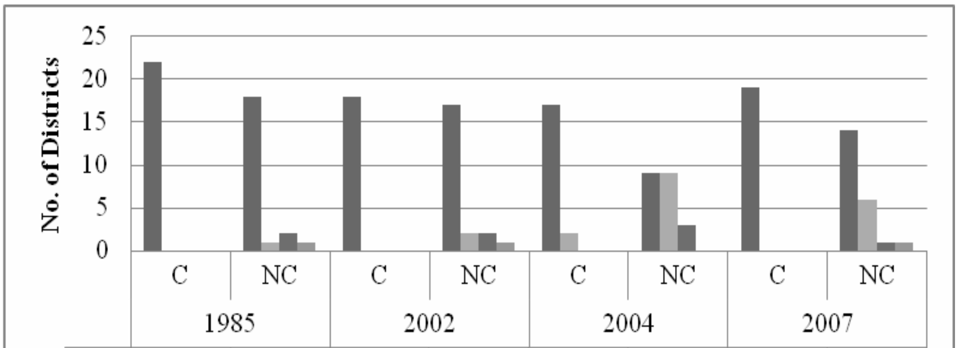
But the worrying feature in this year was that the non-command areas of as many as 10 districts were under semi-critical and three were under the critical category. Even the command areas in two districts came under the semi-critical category during the same year. In 2007, two of the districts slipped into the semi-critical category (Medak and Nizamabad), while two slipped into the critical category (Anantapur and Ranga Reddy), as far as the overall groundwater development was concerned. However, the situation with respect to Non-command areas was found to deteriorate as 12 districts were under the safe category, 8 districts were under semi-critical, while one each came under the critical and the over exploited categories. On the other hand, the situation in command areas seems to have improved as 19 districts were under the safe category.

Figure 2: Districts Falling under Different Categories in AP



	1985	1993	2002	2004	2007
S	22	22	16	17	18
SC	0	0	5	5	2
C	0	0	1	0	2
OE	0	0	0	0	0

Figure 3: Districts under Different Categories across Command and Non-Command Areas in AP



	1985		2002		2004		2007	
	C	NC	C	NC	C	NC	C	NC
S	22	18	18	17	17	9	19	14
SC	0	1	0	2	2	9	0	6
C	0	2	0	2	0	3	0	1
OE	0	1	0	1	0	0	0	1

Table 11: Region-wise Percentage of Assessment Units (*Mandals*) Falling under Different Categories in AP

Year/ Region	Safe			Semi-Critical			Critical			Over Exploited		
1985	C	NC	Overall	C	NC	Overall	C	NC	Overall	C	NC	Overall
Coastal Andhra	NA	NA	92	NA	NA	3.0	NA	NA	2.8	NA	NA	2.6
Rayalaseema	NA	NA	79	NA	NA	7.3	NA	NA	8.5	NA	NA	5.6
Telangana	NA	NA	73	NA	NA	21.0	NA	NA	2.9	NA	NA	2.7
Andhra Pradesh	NA	NA	81	NA	NA	11.2	NA	NA	4.1	NA	NA	3.2
1993												
Coastal Andhra	NA	NA	92	NA	NA	1.6	NA	NA	0.5	NA	NA	0.2
Rayalaseema	NA	NA	90	NA	NA	6.0	NA	NA	3.0	NA	NA	0.0
Telangana	NA	NA	90	NA	NA	7.6	NA	NA	1.3	NA	NA	0.4
Andhra Pradesh	NA	NA	91	NA	NA	5.0	NA	NA	1.4	NA	NA	0.3
2002												
Coastal Andhra	100	100	92.0	1.1	8.7	2.6	0.0	2.1	1.2	0	6.6	3.7
Rayalaseema	100	52.6	60.7	0.0	16.8	12.0	1.6	10.8	9.4	0	20.7	17.9
Telangana	85.7	61.9	68.5	1.5	21.2	15.7	0.0	5.8	4.7	0	12.8	10.7
Andhra Pradesh	99.4	72.9	75.9	1.0	16.3	9.8	0.2	5.9	4.3	0	12.8	9.6
2004												
Coastal Andhra	92.9	75.3	86.4	3.9	9.4	5.9	0.0	3.1	1.6	3.2	11.5	6.1
Rayalaseema	96.7	38.4	47.0	0.0	20.3	20.5	0.0	7.8	6.0	3.3	33.6	26.5
Telangana	89.5	44.9	54.8	5.3	21.6	20.1	1.5	10.2	8.1	3.8	22.8	16.8
Andhra Pradesh	92.5	52.5	65.3	3.8	17.6	14.7	0.4	7.5	5.1	3.4	22.0	14.7
2007												
Coastal Andhra	97.6	80.6	90.2	0.7	11.5	5.6	0.0	3.5	1.2	1.0	3.8	2.3
Rayalaseema	84.8	35.8	45.7	1.5	23.9	18.8	3.0	11.1	10.7	10.6	29.2	24.8
Telangana	88.1	56.7	64.9	9.0	21.1	19.5	0.7	8.2	6.7	2.2	13.8	8.9
Andhra Pradesh	93.2	59.0	70.6	3.1	18.8	14.0	0.6	7.4	5.4	2.7	14.5	9.7

Note: 1. Data compiled from Groundwater Resource Estimated Reports different years, Department of Ground Water, GoAP.
2. C=Command (*ayacut*); NC-Non-Command (non-*ayacut*); Total=Overall (both command and non-command areas).

Stage of Groundwater Development by Assessment Units (*Mandals*)

As far as the proportion of assessment units (both command and non-command areas) falling under safe category was concerned, the share of safe assessment units at the aggregate level remained the same (92%) during 1985, 1993 and 2002, after which it declined in 2004 (86.4%) and thereafter, again increased in 2007 (90.2%). While in 1985, the performance of Telangana Region was the least compared to the other two regions, its performance in 1993 was similar to that of Rayalaseema Region. However, from 2002 onwards, the situation in Rayalaseema Region became worse than the other two regions. The Telangana Region followed a similar trend as that of AP. The proportion of assessment units under the safe category in the command areas in the Telangana Region was lesser when compared to other two regions, except in 2007 (data in this regard are available only after 2002 onwards). Moreover, the percentage of assessment units under the safe category showed a declining trend in the Rayalaseema Region. With regard to the percentage of safe category, the assessment units in the districts under the non-command areas, the trend observed in Coastal Andhra was the same as that of AP (percentage of safe assessment units declined in 2004 and again increased in 2007). One important observation is that in 2002, all the regions performed better as the number of assessment units falling under the safe category are more compared to 2004 and 2007. However, the situation in Rayalaseema Region worsened in 2007 compared to 2004, while in other two regions and also at the aggregate level, there is improvement.

The overall percentage of assessment units falling under the semi-critical category across regions was more in 2004 (14.7%) and less in 1993 (5%) at aggregate level. Except in 2004, the overall percentage of assessment units falling under the semi-critical category in the command areas were found to be more in Telangana Region than in the other two regions. Moreover, an increasing trend was also observed in the command areas of this region over the years. No single assessment unit was under semi-critical category in the command areas of the Rayalaseema Region during the years 2002 and 2004. As far as the non-command areas at the aggregate level were concerned, the percentage of assessment units falling under the semi-critical category showed an increasing trend from 16.3% in 2002 to 18.8% in 2007. Except in 2007, the overall percentage of assessment units falling under the semi-critical category in the non-command areas were more in the Telangana Region than in the other two regions. However, Rayalaseema Region overtook Telangana in 2007.

Assessment units (at the aggregate level for both command and non-command areas) falling under the critical category increased over the years except in 1993. In Rayalaseema, the percentage of assessment units under the critical category at the aggregate level was relatively higher than the other two regions (lowest in Coastal Andhra Region), and greater than the percentage of overall Andhra Pradesh. However, fluctuations were observed during these years (decreasing in 1993 and 2004; increasing in 2002 and 2007). But in the Telangana Region, the percentage of assessment units falling under this category were relatively lower than in the Rayalaseema Region. Except in 2004, the percentage of assessment units falling under the critical category in the command areas were more in Rayalaseema Region (2002 and 2007) than in the other two regions. No single assessment unit was under the critical category in the command areas of the

Coastal Andhra Region during the years 2002, 2004 and 2007. Likewise, a similar trend (with respect to the assessment units falling under the critical category) was also observed in case of the non-command areas of the Rayalaseema Region. In case of Coastal Andhra, the percentage of assessment units falling under the critical category increased marginally.

At the aggregate level, the percentage of assessment units falling under the over exploited category ranged from 0.3% in 1993 to 14.7% in 2004. Except in 1993, the overall percentage of assessment units falling under the over exploited category at the aggregate level was more in Rayalaseema than in the other two regions. Moreover, the overall percentage of assessment units falling under the over exploited category increased both at the aggregate level and also across all the regions, except in 1993. However, the percentage of assessment units falling under the over exploited category was very low in Coastal Andhra compared to the other two regions (except 1985 and 1993), and it was also lower than overall Andhra Pradesh. In 2002, no single assessment unit came under this category in the command areas across all regions. A high percentage of assessment units was recorded in 2004 for all the regions, compared to the other years, except, in the Rayalaseema Region, where higher percentage of assessment units were recorded in 2007. The trend in the non-command areas across different regions showed that Coastal Andhra performed better than the other two regions - the percentage of assessment units falling under the over exploited category were lesser here compared to the other two regions. The Rayalaseema Region had a higher percentage of over exploited units, followed by Telangana in all the estimated years. A high proportion of over exploited units was recorded in 2004 in all the regions.

Table 12: DPAP and Non-DPAP Districts-wise Percentage of Assessment Units in AP

Scheme/ Year	Categorization of Assessment Units											
	Safe			Semi-Critical			Critical			Over Exploited		
DPAP	C	NC	Total	C	NC	Total	C	NC	Total	C	NC	Totall
1985	NA	NA	82.4	NA	NA	9.8	NA	NA	4.4	NA	NA	3.2
1993	NA	NA	92.9	NA	NA	5.2	NA	NA	1.4	NA	NA	0.0
2002	93.9	64.1	70.1	0.0	15.7	12.5	0.6	7.3	6.2	0.0	13.1	11.1
2004	94.5	50.4	56.3	1.2	21.0	19.8	0.0	7.2	6.0	4.3	21.0	17.7
2007	92.9	57.1	64.1	1.8	20.4	16.8	1.2	7.3	6.6	4.2	15.2	12.5
Non-DPAP												
1985	NA	NA	79.9	NA	NA	13.0	NA	NA	3.6	NA	NA	3.4
1993	NA	NA	88.5	NA	NA	4.6	NA	NA	1.3	NA	NA	0.6
2002	100	89.0	83.4	1.6	17.5	6.3	0.0	3.3	1.9	0.0	12.5	7.5
2004	91.4	56.4	77.1	5.1	11.3	8.0	0.6	8.0	4.0	2.9	23.7	10.7
2007	94.0	63.9	79.0	3.8	16.1	10.3	0.3	7.8	3.8	1.9	13.1	6.1
AP												
1985	NA	NA	81.4	NA	NA	11.2	NA	NA	4.1	NA	NA	3.2
1993	NA	NA	91.1	NA	NA	5.0	NA	NA	1.4	NA	NA	0.3
2002	99.4	72.9	75.9	1.0	16.3	9.8	0.21	5.9	4.3	0.0	12.8	9.6
2004	92.5	52.5	65.3	3.8	17.6	14.7	0.42	7.5	5.1	3.4	22.0	14.7
2007	93.2	59.0	70.6	3.1	18.8	14.0	0.62	7.4	5.4	2.7	14.5	9.7

Note:- 1. Data compiled from different Groundwater Resource Estimated years Reports, Groundwater Department, GoAP.

2. C-Command (ayacut); NC-Non Command (Non-ayacut); Total-overall (both Command and Non-Command areas).

3. In 1985 and 1993 groundwater resource estimations calculated/worked out only taken the overall- wise Groundwater Resource(both Command and Non-Command area together) and other Resource Estimations are taken in Command, Non-Command and overall-wise (2002, 2004 and 2007)

DPAP & Non-DPAP Districts:

With respect to the percentage of assessment units falling under the safe category across DPAP and non-DPAP Districts, at the aggregate level, while the performance of DPAP districts were better than that of the non-DPAP districts during1985 and 1993, the non-DPAP districts performed better than DPAP districts during the other estimated years (2002, 2004 and 2007). In 2004, the percentage of assessments units falling under the safe category across DPAP and non-DPAP districts, in non-command areas was found to be lesser compared to the other years.

The percentage of assessment units falling under the semi-critical category under DPAP was higher than the non-DPAP districts at aggregate level in all the years except in

1985. While, in the command areas, the percentage of assessment units falling under the semi-critical category under non-DPAP was higher than in the DPAP districts, in case of non-command areas, the reverse trend (the percentage of assessment units falling under the semi-critical category are more in DPAP than in the non-DPAP districts) was observed except in 2002.

Furthermore, the percentage of assessment units falling under the critical category under DPAP was higher than the non-DPAP districts at the aggregate level. Except, in 2002, the percentage of assessment units falling under the critical category in the non-command areas of non-DPAP districts was higher than the DPAP districts.

Similarly, the percentage of assessment units falling under the over exploited category in DPAP Districts was higher than the non-DPAP districts, at the aggregate level, except in 1985 and 1993. And the percentage of assessment units falling under the over exploited category in the command areas of DPAP districts were higher than the non-DPAP districts, except in 2002. A similar trend was also observed in case of the non-command areas (the percentage of assessment units was more in DPAP than non-DPAP districts), except in 2004.

When the performances of the command and non-command areas are compared within their respective districts (DPAP and Non-DPAP Districts), the command areas are found to be performing better than their non-command counterparts in all the estimation years (2002, 2004 and 2007).

The Micro Picture: Over Exploited Villages

In Andhra Pradesh, the number of over exploited villages has gone up from 1481 in 2002 to 3449 in 2008. This number increased to 4190 during 2004 due to the severe drought conditions (Table 13). At the state level, the number has more than doubled over a period of six years. Across the regions, the increase almost doubled in Coastal and Rayalaseema Regions - the number of over exploited villages went up by almost three times in Telangana. Though these figures are based on the sample wells, they reflect the severity of groundwater depletion at the micro level. Among the assessment units, about 30% reported the depletion repeatedly. The proportion of repeated units are the highest in Rayalaseema (50%) followed by Telangana (40%) and Coastal Andhra (10%). The average number of times repeated in this depletion category (other than safe category) was more in non-command areas when compared to command areas in all the three regions. Similarly, the percentage of assessment units repeated and the average number of times repeated were more in DPAP districts than in the non-DPAP districts. The extent of repeated units was 35% in the DPAP districts, as against 21% in the non-DPAP districts.

Table 13: District/Region-wise Distribution of Over Exploited (OE) Villages in OE Basins

District/ Region	No. of Over Exploited Villages			Percentage of Assessment Units Reporting Repeated Depletion
	2002	2005	2008	
Srikakulam	0	0	0	2.6
Vizianagaram	0	4	0	0
Visakhapatnam	4	0	0	4.7
East Godavari	0	32	0	5.3
West Godavari	132	152	118	23.9
Krishna	0	34	40	10
Guntur	0	11	4	0
Prakasam	28	145	121	26.8
Nellore	19	150	123	8.7
Coastal Andhra	**183**	**528**	**406**	**9.6**
Chittoor	89	569	601	51.5
Cuddapah	499	345	379	68.6
Anantapur	133	385	420	68.3
Kurnool	5	106	46	9.3
Rayalaseema	**726**	**1405**	**1446**	**50**
Mahbubnagar	36	378	158	48.4
Ranga Reddy	112	390	332	37.8
Medak	45	380	247	47.8
Nizamabad	150	196	231	75
Adilabad	0	47	77	3.8
Karimnagar	38	294	153	45.6
Warangal	125	330	208	44
Khammam	9	34	16	8.7
Nalgonda	57	208	175	50.8
Telangana	**572**	**2257**	**1597**	**39.8**
Andhra Pradesh	**1481**	**4190**	**3449**	**30.3**

Source: GoAP, Groundwater Department, Hyderabad.

Trends in Groundwater Irrigation

The area under well irrigation reflects the changes in groundwater development. Historically, the major sources of irrigation in AP are tanks, canals and wells in the same order of importance. Till the early 1970s, tanks were the dominant sources of irrigation in the Telangana and Rayalaseema Regions, while canals were the main source in the Coastal Andhra Region. After the 1970s, well irrigation emerged as the major source in

Telangana and Rayalaseema Regions. Over a period of four and half decades, the proportion of area under irrigation in the state went up - from 27% in 1963 to 40% in 2008 (Table 14). The growth in the area under irrigation was found to be more in the Telangana Region (from 21% to 38% between 1963 and 2008) when compared to the Coastal and Rayalaseema Regions, resulting in a substantial decrease in regional disparities. During this period, the intra-regional disparities also decreased in all the three regions.

Across the sources, the area under canals increased by three percentage points in Coastal Andhra and one percentage point in Telangana Region, between 1963 and 2008. The Coastal Andhra Region experienced 4% decline in the area under canals between 1993 and 2008, which could be due to the severe scarcity of water in the major systems during the period ending in 2008. After taking this into account, the increase in area under canal was found to be more in the Coastal Andhra Region between 1963 and 1983, which stagnated after 1983. Similarly, the picture is of stagnation or marginal improvement in the case of Rayalaseema. Inter as well as intra-regional disparities in the area under canals decreased substantially over the period of 45 years. While tank irrigation declined in all the regions, well irrigation gained more in Telangana when compared to other Regions. The increase in well irrigation was the main reason for the overall decline in disparities in the state.

Table 14: Source-wise Area Irrigated (Area Irrigated by Source/Net Irrigated Area) Across Regions of AP

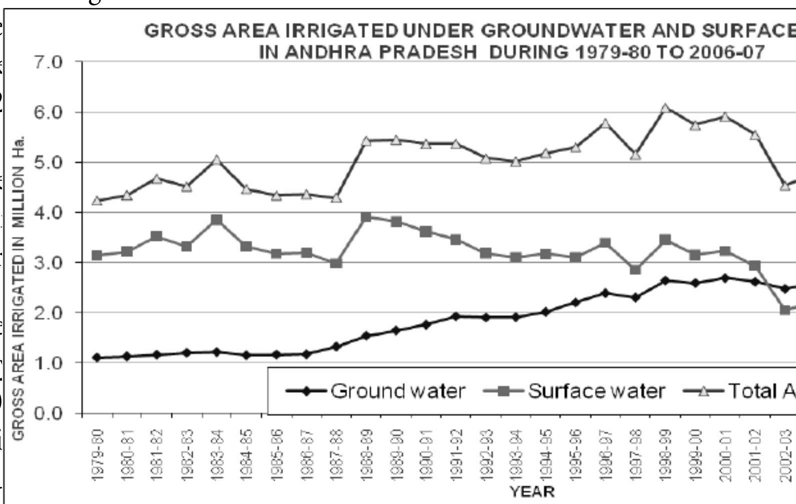
Triennium Ending	Canal			Tank			Well		
	Coastal Andhra	Rayala-seema	Telan-gana	Coastal Andhra	Rayala-seema	Telan-gana	Coastal Andhra	Rayala-seema	Telan-gana
1963	46	19	14	24	32	49	5	24	12
1973	62	29	27	26	29	39	9	37	26
1983	63	31	27	23	21	37	12	44	32
1993	60	25	21	19	15	20	16	57	54
2003	57	20	17	18	12	15	21	66	64
2008	55	19	13	15	8	12	25	72	72

Source: Data compiled from Season and Crop Reports various years', Directorate of Economics & Statistics, GoAP, Hyderabad

Figure 4: Gross Area Irrigated by Groundwater and Surface Water

Source: Data compiled from Season and Crop Reports various years', Directorate of Economics & Statistics, GoAP, Hyderabad.

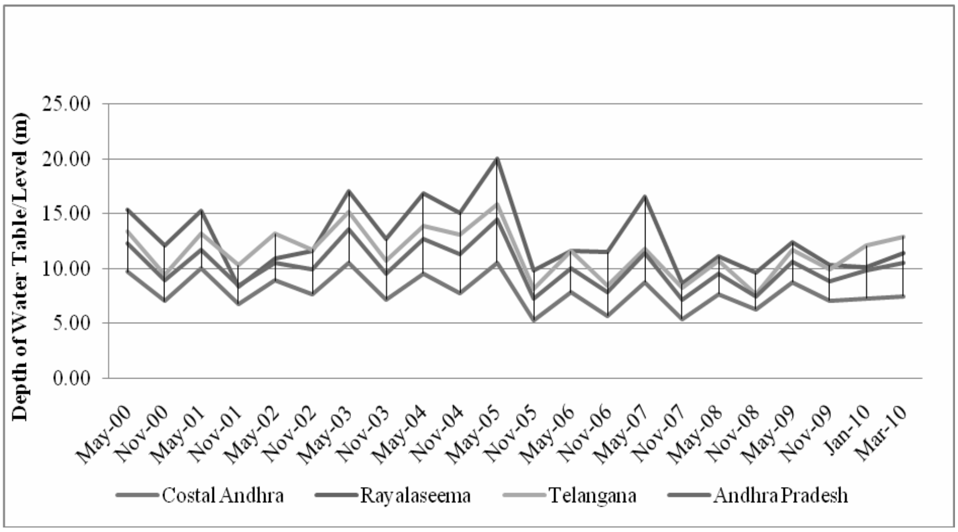
Telangana and Rayalaseema have experienced drastic shifts in the composition of irrigation. By 1980s, well irrigation was the dominant source of irrigation, replacing tank irrigation in the two regions. Though canal irrigation still dominates in the Coastal Andhra Region, well irrigation has replace
relative shares of the three important sourc
irrigation in Telangana has gone up from 12
the case of canal irrigation (Table 14). Even
fold increase in the area under wells, whil
55%. The proportion of area under canals
though it experienced an increase in well ir



The area under groundwater irrigation is ne
surface water sources put together, especiall
The population of wells increased from 0
million bore wells) in 1971 to about 2.5 mi
bore wells) in 2007. The area under grou
million hectares to about 2.8 million hectares during the same period. It can be seen that the area irrigated per well is almost constant, but water is being drawn from deeper depths. The increase in exploitation of groundwater in some places is alarming and may not be sustainable unless measures are taken to control its use by increasing its efficiency.

On an average, the density of wells increased from five wells to over 10 wells per sq km. However, in hard rock areas, it is over 20 wells per sq km, while in some pockets it is as high as 100 wells per sq km. Consequently, well yields decreased considerably and water levels went down alarmingly. About 48% of the net groundwater availability is in command areas, which constitute about 23% of the state's geographical area, and where groundwater utilization is only 25%. Here, the problem is of surplus, resulting in water logging and water quality problem.

Figure 5: Region-wise Average Depth of Water Level in Pre- and Post-Monsoon Periods



Source: GoAP, Ground Water Department, Hyderabad.

The existing surface water bodies and canal seepages are able to contribute about 4% to 5% towards groundwater recharge, and about 9% to 10% is added by way of natural infiltration. Large scale recharge measures implemented considering riparian rights in the past could increase recharge only by 1%, which also requires proper maintenance and is not very cost- effective (Kumar, 2008). Water levels during the pre- and post-monsoon periods indicate that groundwater depths are highly linked to rainfall with a little lag. Water tables have gone up to below 10 m range in both Telangana and Rayalaseema Regions during 2004-05 and 2008-09, while it increased during 2010 (Fig. 5). Groundwater depths are the highest in the Rayalaseema Region during most of the years. The impact of groundwater depletion adversely affects the small and marginal farmers disproportionately (Reddy, 2004). Though the small and marginal farmers are now able to invest in groundwater extraction due to availability of cheap technologies, they are often at a disadvantageous position while competing with the large farmers in well deepening. As a result, they become the first victims of groundwater depletion and pay huge price in terms of direct and indirect costs.

Free Power and Groundwater Development

Groundwater development and degradation are often validly linked to the energy policies of the state. Subsidies on power (often charged at flat rate irrespective of the quantity consumed) are expected to further aggravate groundwater mining. While there are pros and cons of power subsidies on groundwater in specific and agriculture development in general, it is arguably detrimental from the resource (environment) point of view. The arguments in favour of power subsidies are that they enhance the viability of farming and increase the access to water either through water markets or otherwise, especially among the small and marginal farmers. On the other hand, it is argued that small and marginal farmers become the victims of over exploitation (Reddy, 2004). In either case, resource degradation is imminent, resulting in 'tragedy of commons' in the long run.

The announcement of free power to farmers in 2004 by the AP Government is seen as populist act that is unmindful of economic and environmental consequences. It was argued that the policy would not only increase the power consumption adding to the burden of the exchequer, but also aggravate the problem of the already dwindling resource. Here, an attempt is made to assess the impacts of free power policy using the official data. Different indicators are examined to assess the impact of free power. These indicators include growth in agricultural service connections, energisation of wells and power consumption. None of the indicators have revealed any significant changes after the introduction of free power in 2004. The number of agricultural service connections have reached their peak during 2000-01 and declined drastically during 2004-05 (Table 15). A similar trend was observed across the regions though the changes are more substantial in the Telangana and Rayalaseema regions when compared to the Coastal Andhra Region. In fact, the Coastal Andhra Region recorded only a marginal increase in the number of service connections during 2004-05. This could be due to the severe drought conditions prevailing between 2001 and 2004. The impact is severe in the rain-fed regions of Telangana and Rayalaseema. Though there was substantial improvement in the number of service connections during 2006-07, the number was much below the 2000-01 peak. Moreover, the increase was mainly due to better groundwater situation during the post-2004 period and cannot be attributed to the free power policy of the state. This is evident from the proportion of wells energised during this period and the actual power consumption.

The proportion of wells energised shows a secular trend over the period of 25 years in the Coastal and Rayalaseema regions, while the Telangana Region recorded a jump in the energisation of wells after 1993-94 (Fig. 6). By mid-1990s, Telangana over took Rayalaseema in well energisation. In fact, the share of Telangana in well energisation was the main reason for the higher state average after mi- nineties. However, such shifts

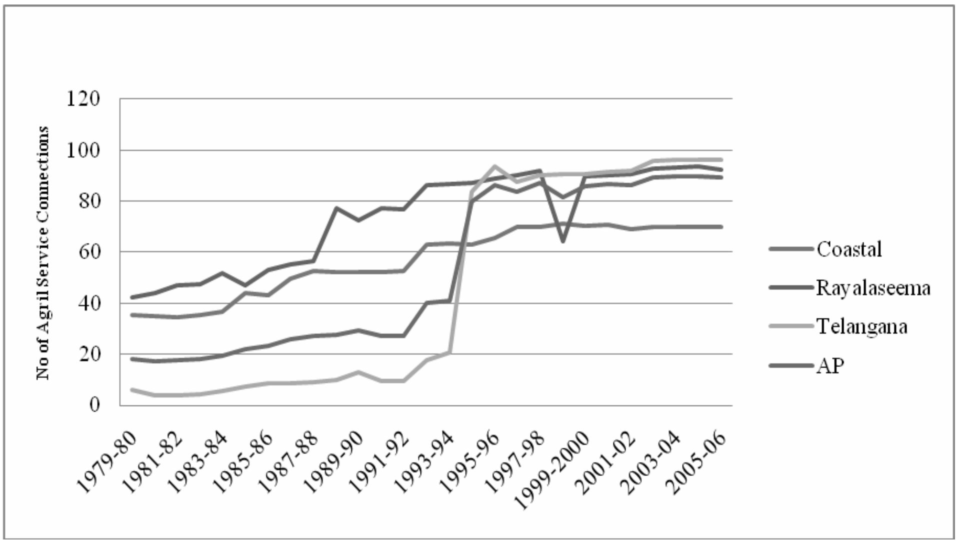
Table 15: Year-wise Growth in Agricultural Service Connections across Regions

Region	No. of Agricultural Service Connections during the Reference Years				
	1984-85	1993-94	2000-01	2004-05	2006-07
Coastal Andhra	8430	20085	22239	22586	25015
Rayalaseema	4632	23109	26001	15656	17624
Telangana	31182	58983	70053	26518	44338
Andhra Pradesh	44244	102177	118293	64760	86977

Source: 1. Data compiled from APTRANSCo Ltd, Power Development in Andhra Pradesh (Statistics) various years, and Hyderabad.

2. Data compiled from Statistical Abstract of Andhra Pradesh various years, Directorate of Economics & Statistics, GoAP, Hyderabad.

Figure 6: Region-wise Proportion of Wells Energised Over the Years

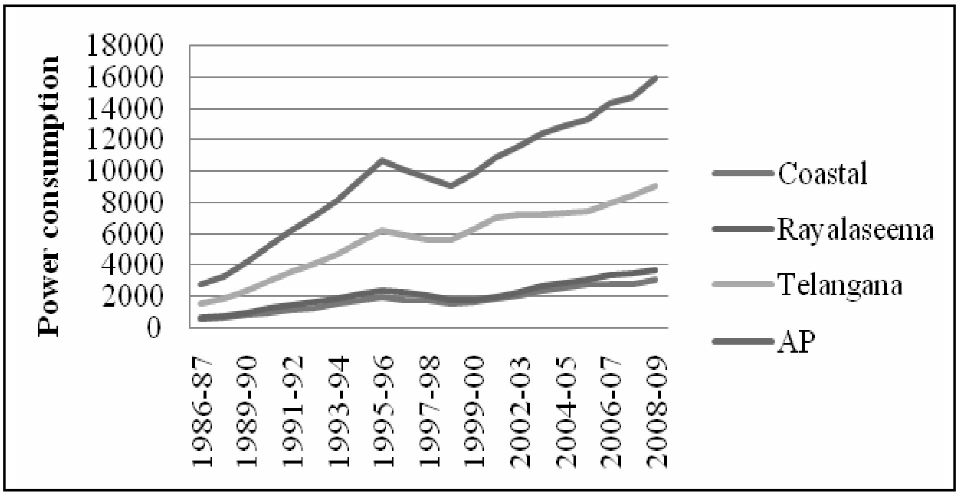


Source: 1. Data compiled from APTRANSCo Ltd, Power Development in Andhra Pradesh (Statistics) various years, and Hyderabad.

2. Data compiled from Statistical Abstract of Andhra Pradesh various years, Directorate of Economics & Statistics, GoAP, Hyderabad.

or changes are not evident after the advent of free power policy in 2004. This is also evident in the case of power consumption across regions, which show a smooth trend (Fig. 7). The consumption of energy in the DPAP districts, which have majority of the bore wells and electric pump sets, has also not shown any shift after the advent of free power policy (Fig. 8).

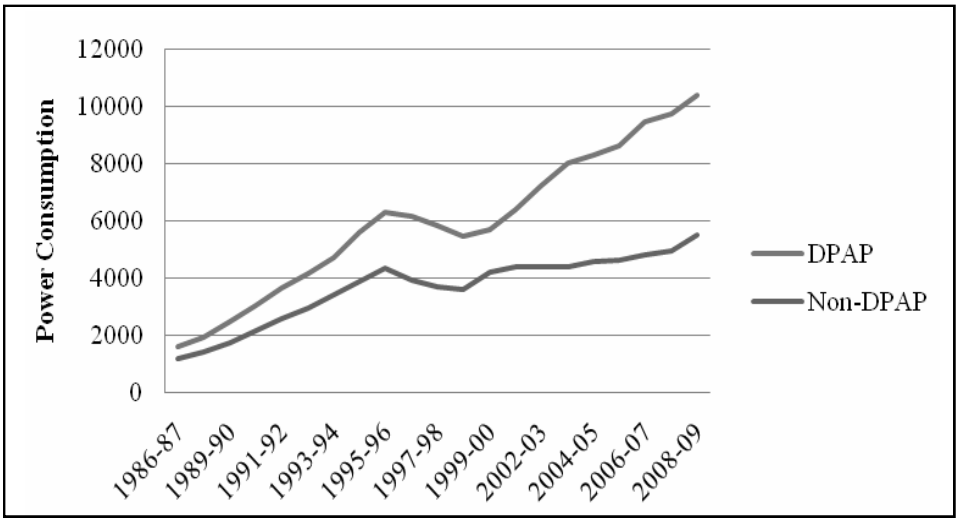
Figure 7: Three Year Moving Average of Electricity Consumption in Agriculture by Regions



Source: 1. Data compiled from APTRANSCo Ltd, Power Development in Andhra Pradesh (Statistics) various years, and Hyderabad.

2. Data compiled from Statistical Abstract of Andhra Pradesh various years, Directorate of Economics & Statistics, GoAP, Hyderabad.

Figure 8: Three Year Moving Average of Energy Consumption in Agriculture by DPAP and Non-DPAP Districts

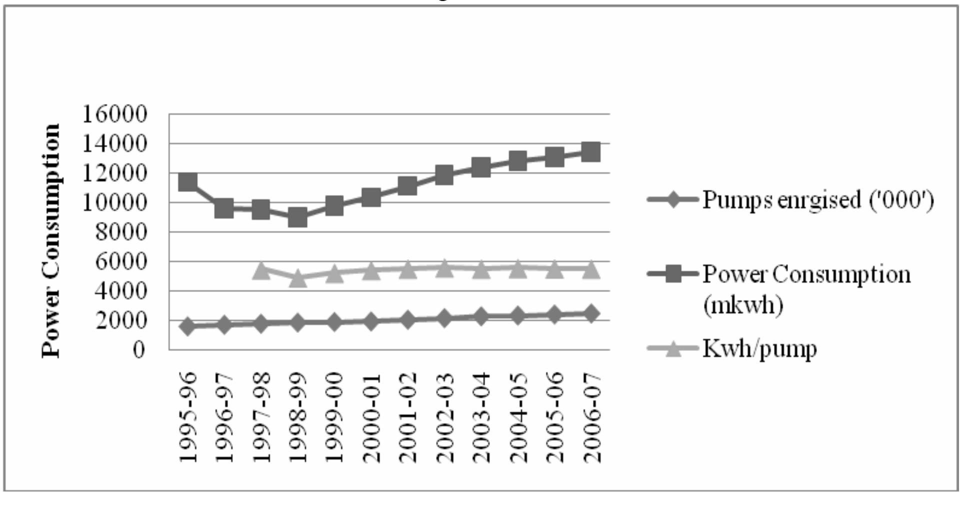


Source: 1. Data compiled from APTRANSCo Ltd, Power Development in Andhra Pradesh (Statistics) various years, and Hyderabad.

2. Data compiled from Statistical Abstract of Andhra Pradesh various years, Directorate of Economics & Statistics, GoAP, Hyderabad.

Interestingly, the increasing trends observed in the case of pumps energised and the total power consumption in each year, the per pump power consumption has remained the same over the years (Figure 9). This indicates that there is no change in power consumption at the individual level, before or after free power policy. This could be due to supply regulation of power at the state level. In fact, farmers complain that they get less than seven hours of supply against the promised nine hours of supply per day. As a result, the aggregate power consumption has gone up from about 1200 million kilowatt hours in 2004-05 to about 13500 million kilowatt hours. The financial burden of the free power policy is about Rs.1350 crores at the rate of Re.1 per kilowatt hour. However, as the data clearly indicates, this burden is not due to the free power policy. For, power was already subsidised heavily even prior to the free power policy. Under the flat rate regime, the state was collecting only about Rs.3 crores at the rate ranging from of Rs.1800 to Rs.2640 per connection respectively for 3 and 5 HP pumps. Since there was no increase in power consumption (apart from the normal), the free power burden is mainly in terms of loss due to the loss of revenue from the flat rate collections from the existing number of energised wells. At the present level of energisation (24.48 lakh pumps in 2006-07) with an average flat rate of Rs. 2200 per pump per year the burden on the state is Rs. 538.56 crore, which has gone up from more than Rs. 400 crores during 2004-05. In effect, the state is losing more than Rs. 500 crores per year and this would go up over the years with increased number of energised wells. But for the supply

Figure 9: Three Year Moving Average of Energisation and Electricity Consumption in Agriculture



Source: 1. Data compiled from APTRANSCo Ltd, Power Development in Andhra Pradesh (Statistics) various years, and Hyderabad.
2. Data compiled from Statistical Abstract of Andhra Pradesh various years, Directorate of Economics & Statistics, GoAP, Hyderabad

regulation, the burden would have been higher. The state has adopted a dual policy of populism coupled with supply regulation which helped in checking the financial burden and also in maintaining the *status quo* in groundwater development. That is, the free power policy has not triggered an increased pace in the race for groundwater exploitation. The benefit to the farmers is only marginal (Rs.2200 per pump) on an average, if not negative, considering the reduced hours of power supply. The benefits seem to be more psychological rather than real to the farming community.

On the whole, the spatio-temporal analysis of groundwater development has been looked from multiple dimensions and the assessments are re-emphasised from all the angles. The analysis brings out some interesting aspects. These include:

- The methodological basis of groundwater assessment is rather weak and hence, the assessments may have limited use for the farming communities.
- There is a secular trend in groundwater development over the years.
- This trend is only broken due to severe droughts or very good monsoons.
- Regional variations indicate that Telangana had a late entry in the case of mechanisation and enrgisation of groundwater exploitation, though it has over taken the Rayalaseema Region by mid nineties.
- The level of groundwater development and its adverse impacts are more severe in Rayalaseema Region.
- There is imbalance in the development and available groundwater in the command and non-command areas. While the command areas have under-development of groundwater, the non-command areas have excess development.
- Similarly, DPAP districts face the adverse impacts of groundwater development when compared to the non-DPAP districts.
- Though the level of groundwater development at the aggregate level is not alarming, the micro situation is a cause of concern as the number of villages included under the over exploited category is increasing over the years.
- The trends in groundwater development are reflected very well in the area irrigated under wells. Though the area under well irrigation is expanding, the area irrigated per well is either stagnant or declining.
- The micro impacts are clearly seen in the case of well failures and the resulting farm distress in some regions.
- The free power policy of the state has neither helped in expanding the area under wells nor reduced the burden on the farmers substantially.

- The dual policy of free power and supply regulation does not seem to have any significant impact on agriculture.

IV Factors Influencing Groundwater Development

At this juncture it would be pertinent to examine the factors determining the variations in groundwater development across the districts in the state. For this purpose, multiple regression analysis has been adopted using a number of indicators that influence groundwater development. The basic specification is as follows:

$$GWD_{dt} = F(NF_{dt}, EF_{dt}, SF_{dt}, DF_{dt}) + U_{dt},$$

Where,

GWD_{dt} = Groundwater Development measured in terms of extent of utilisation with reference to potential in district '*d*' at time '*t*'.

NF_{dt} = The set of natural factors such as rainfall, irrigation, irrigation intensity, surface water bodies, canal irrigation, cropping intensity, etc., in the district.

EFd_{dt} = Economic Factors such as per capital income, extent of poverty, number of bore wells, number of agricultural power connections, etc., in the district.

SF_{dt} = Social Factors such as Human Development Index, literacy level, etc., in the district.

DF_{dt} = Development Factors such as coverage under watershed development programme in the district.

U_{dt} = Error term.

The selection of independent variables is based on the theoretical considerations and the availability of data at the district level. The variables are drawn mainly from different sources such as statistical abstracts, season and crop reports, minor irrigation census, population census and departmental records. An exhaustive list of indicators that are likely to influence the performance was prepared. All these variables were tried in different combinations and permutations. But, some of the variables, though important, did not find place in the specifications due to various reasons including multi-collinearity, non-significance and also the absence of variation. The details of variable measurement and their theoretical/expected impact on groundwater development are presented in Table 16.

Table 16: Measurement and Expected Signs of the Selected Variables

Variable	Measurement	Expected Impact
Actual Annual Rainfall (AARF)	In mm per year	+ve
Irrigation Intensity (II)	Gross/net area irrigated in %	+ve
No. of Dug wells	Actual numbers	-/+ve
No. of Tube Wells	Actual Numbers	+ve
Per Capita Income (PCI)	Rupees per year	+ve
No. of Tanks	Actual Numbers	-/+ve
Human Development Index (HDI)	Index of different indicators	+/-ve
Area under Canal Irrigation	In acres	-ve
Cropping Intensity (CI)	Gross/net cropped area in %	+ve
Area under Groundnut Crop	In acres	+ve
% of Below Poverty Line (BPL) Population	Percentage	-ve
% of Literate Population	Percentage	+ve
Number of Power Connections to Agriculture	Actual Number	+ve
WSD Coverage	Area in Hectares	-/+ve
Human Poverty Index (HPI)	Index	-ve
Area under Groundnut	In Acres	+ve

Linear regressions applying Ordinary Least Squares (OLS) were estimated to regress the dependent variable (GWD) against the selected independent variables (SPSS package). Regressions were run on cross sectional data across the districts. Various permutations and combinations of independent variables were used to arrive at the best fits. The estimates were carried out for all the five groundwater assessment years to assess the robustness of the estimates. Further, estimates were carried out for command/non-command and DPAP/non-DPAP areas as well, though the results are presented for non-command and DPAP areas only. Multi-collinearity between the independent variables was checked using the Variance Inflation Factor (VIF) statistic. Multi-collinearity is not a serious problem as long as the value of VIF is below 2. The best-fit specification was selected for the purpose of final analysis for each dependent variable. The indicative results are presented in Table 17 while the detailed results along with the descriptive statistics are presented in the Annexure.

Table 17: Factors Influencing Groundwater Development over the Years in Non-Command and DPAP Areas

Variable	YEAR				
	1985	1993	2002	2004	2007
Overall					
Irrigation Intensity (II)	NA	+	NA	+	+
No. of Dug wells	NA	NS	NA	NA	NA
No. of Tube Wells	NS	NS	NA	+	-
Per Capita Income (Rs./Year)	NA	NA	NA	NA	NS
No. of Tanks	NA	NA	NA	-	NA
Human Development Index (HDI)	NA	+	+	NA	NA
Area under Canal Irrigation (Acres)	NA	-	-	-	-
Cropping Intensity (CI)	NA	NA	+	NA	NA
Area under Groundnut Crop (acres)	NA	NA	+	NA	NA
Actual Annual Rainfall (mm)	NA	NA	NA	+	-
% of Below Poverty Line (BPL) Population	+	NA	NA	NA	NA
% of Literate Population	+	NA	NA	NA	NA
Number of Power Connections to Agriculture	+	NA	NA	NA	NA
Non-Command Areas					
Irrigation Intensity (II)	NA	+	+	NA	NA
No. of Dug wells	NA	NS	NS	NA	NA
No. of Tube Wells	NA	NS	+	+	NA
Per Capita Income (Rs./Year)	NA	NA	NA	NS	NA
No. of Tanks	+	NA	NA	-	NA
Human Development Index (HDI)	NA	+	NS	NA	NA
Area under Canal Irrigation (Acres)	NA	-	NA	NS	-
Cropping Intensity (CI)	NS	NA	NA	NA	+
Actual Annual Rainfall (mm)	NA	NA	NA	-	NS
WSD (Area covered in Hectares)	NA	NA	NS	-	NA
% of Below Poverty Line Population	NA	NA	NS	NA	NA
% of Literate Population	+	NA	NA	NA	+
Number of Power Connections to Agriculture	+	NA	NA	NA	+
Area under Groundnut (acres)	-	NA	NA	NA	NA
DPAP Areas					
Actual Annual Rain Fall (mm)	-	-	NA	-	-
Number of Power Connections to Agriculture	+	NA	NA	NA	-
Area under Canal Irrigation	-	-	-	-	-
Cropping Intensity (CI)	NA	+	+	NA	NA
WSD (Area covered in Hectares)	NA	NA	+	NA	NA
% of Below Poverty Line (BPL) Population	NA	NA	NS	NA	NA
% of Literate Population	NA	+	NA	NA	NA
Irrigation Intensity (II)	NA	NA	NA	NS	NA
Human Poverty Index (HPI)	NA	NA	NA	-	NA

Note: + indicates positively significant; - indicates negatively significant; NS= Not Significant; NA= Not Applicable (not used in the specification). Detailed estimates are presented in the Annexure.

The estimates indicate that not many variables turned out to be significant across the years in both non-command as well as DPAP areas, though the selected specifications explain more than 60% of the variations in the case of non-command areas and more than 80% of the variations in the case of DPAP districts (see Annexure). Most of the indicators have shown up with expected signs. At the state level, the area under canal irrigation turned out significant in four of the five years, with a consistent negative sign indicating that groundwater development is limited in the canal irrigated areas (Table 17). On the other hand, cropping intensity has shown a consistent positive impact in three out of five years. That is groundwater is used more intensively as the area under second and third crops increase. Human Development Index (HDI) turned out to be significant in two of the years with a positive sign. This means that human development could increase groundwater development due to the overall comprehensive development reflected in the HDI. Though the actual rainfall and number of tube wells turned out to be significant in 2004 and 2007, they were not consistent in the sign. Both the variables showed positive impact during 2004 and negative sign during 2007. It may be inferred that rainfall and number of tube wells would increase exploitation of groundwater in drought conditions (2004) while in good rainfall years, the demand would go down coupled with increased supply, resulting in a net negative impact on groundwater development.

In the case of non-command areas, the variables area under canal irrigation and irrigation intensity turned out to be significant in two of the years with signs similar to that of the state level. The number of tube wells, power connections, literacy and HDI revealed a positive impact on groundwater development. In the non-command areas, all these indicators, except the area under canal irrigation, promote groundwater exploitation. The number of tanks was seen to have a positive impact in one year and a negative impact in the other year. Furthermore, it is seen that the actual rainfall and the area covered under watershed development also have a negative impact on groundwater development. That is, in the command areas, watershed development could lead to checking of groundwater exploitation.

However, in the DPAP districts, WSD leads to exploitation, which is also evident at the field level studies (Reddy, *et al.*, 2010). That is, groundwater use in terms of the number of wells tends to increase after the advent of watershed development. Often this results in upsetting the recharge impact of watershed development. The actual rainfall and area under canal irrigation have a more clear negative impact on groundwater development in the DPAP districts, as they turned out to be significant in most of the years. On the other hand, cropping intensity has a positive impact on groundwater development. And literacy, also in line with non-command areas, and state-level impacts, has a positive impact on groundwater development.

Overall, the regression analysis of the factors influencing groundwater development does not prove to be of much help in a better understanding of groundwater management. This is because the policy variables such as WSD, literacy and HDI did not reveal any clear impact towards checking groundwater development. This could be due to the reason that in the absence of groundwater institutions these factors may have limited influence. Besides, our analysis also does not include any institutional variables due to the non-existence of any formal groundwater institutions at the district level. Therefore, it would be pertinent to examine the impact of institutions on groundwater management that are prevalent in some of the districts. The following section examines these aspects in detail, on the backdrop of Andhra Pradesh Farmer Managed Groundwater Systems (APFMGS) experience.

V. Managing Groundwater: Role of Local Institutions

Scientific information on geo-hydrology and groundwater is the domain of scientific community. The technicalities involved in generating such information are believed to be beyond the knowledge of a non-technical person, not to mention the illiterate farmer. But the increasing gap between the scientific information and the user, coupled with the fast deteriorating groundwater situation has led to institutional innovations of groundwater management. Some of the earlier institutional innovations have focused mainly on the community-based collective strategies such as forming rules and regulations for groundwater use and management (Deshpande and Reddy, 1990; World Bank, nd). None of the institutional arrangements based their approach on scientific information. Though some of them have achieved a fair amount of success, their spread and sustainability in the long run was limited, as they were driven by leadership and local conditions. Similarly, the regulator approaches of restricted power supply and no access to formal credit (to those who intend to have a borewell within a radius of 200 metres of another bore well) fail to encourage the farmers towards judicious use of groundwater.

In this context, the initiative of APFAMGS is a 'bottom up' approach grounded on farmer-generated hydrological information at the village level. The initiative is based on a multi-layered approach involving training of farmers for generating hydrological data, estimating water balance, crop water budgeting, participatory cropping decisions, creating awareness with proper communication strategies, etc. There is no incentive or dis-incentive structure linked to the initiatives; rather the focus is on behavioural change towards self-regulation using information and experience. In this section, we try to examine the approach in detail along with its relevance and scalability. The assessment is based on the material available on their official website (www//:apfmgs.org) and our field visits to some of their villages.

History

The APFAMGS project was launched in July 2003 in partnership with farmers for implementing demand side groundwater management - an alternative model to the supply side approach. The project was funded by the Royal Netherlands Embassy, New Delhi, and its implementation was guided by the Food and Agricultural Organization (FAO). The project, in partnership with the local NGOs[1], is implemented in 650 villages spread over 63 hydrological units across seven drought-prone districts[2] of Andhra Pradesh using hydrological boundaries as an operational unit. The main objective of the project is to "equip groundwater farmer users with the necessary data, skills and knowledge to manage groundwater resources available to them in a sustainable manner, mainly through managing and monitoring their own demand". The basic premise is that self-generated scientific data and knowledge will enable farmers to make appropriate farming choices using groundwater. The farming communities make informed decisions using hydrological data developed on the Geological Information System (GIS) platform. Elaborate institutional arrangements with equal representation of men and women were made to implement the programme.

Activities

The main activities include:

- Awareness on the emerging groundwater crisis and groundwater as a 'common good' at the habitation and hydrologic unit level.
- Demystify the science of hydrology through participatory learning, practicing and establishing a new relationship between farmers and groundwater.
- Participatory planning and sharing information through crop water budgeting workshops for evolving common strategies that limit damage to the groundwater system without sacrificing individual interest.
- Steps towards improving crop water efficiency and reduce chemical pollution.
- Introducing groundwater governance, transcending individual holdings and habitations without being coercive through voluntary choices such as reduced pumping, preventing construction of new wells, crop diversification, reduced application of chemical fertilizer/pesticides, etc.

Approach

A comprehensive institutional structure integrating technical and social components was established. At the village level a Ground Water Management Committee (GMC)

1 Nine local NGO partners were involved under a nodal NGO namely Bharathi Integrated Rural Development Society (BIRDS).

2 These districts are: Anantapur, Chittoor, Kadapa, Kurnool, Mahbubnagar, Nalgonda and Prakasam.

is the key institution of the farmers, including men and women. A network of GMC, viz., the Hydrological Unit Network (HUN), is formed at the hydrological unit level. These two are critical for providing 'demonstration effect' of the learnings from the project to the larger community of farmers beyond the project area. The HUNs have a legal status allowing them to receive funds as well as carry out business activities.

Making the farmers water literate is the core of the approach. The first step in this direction is to enhance the farmers' capacity to collect and analyse data on their own. Capacity building and training activities are part of the project components. Formal and informal techniques such as technical training related to recording rainfall, measuring draft from observation wells, cultural shows, practical training, exposure visits, exchange visits and workshops, are included. These capacities are used in the Participatory Hydrological Monitoring (PHM) exercise. In PHM, farmer volunteers[3] monitor water levels from 2026 observation wells (one well for every sq km) every fortnight. The daily rainfall measurement is collected from rain gauge stations from 190 rain gauge stations established for every 5 sq km in the project area. The collected information is displayed for the farmers to take farming decisions. Discharge measurements are also carried out to understand the pumping capacity in 700 monitoring observation wells. This is accomplished by measuring the time taken to fill a known capacity of drum. Along with the discharge, the farmers also measure the drawdown. Based on the measurement, the farmers have a good understanding of the pumping capacity of the wells, well performance, water requirement for different crops and the ways and means to increase the water use efficiency. In this way, science has been demystified and made user friendly for the farmers.

Crop-Water Budgeting (CWB)

The success of demystifying science is reflected in the Crop Water Budgeting (CWB) which helps farmers collectively prepare land use plans depending upon water availability. The CWB is taken up at the village level before the beginning of each season and aggregated at the HUN level. Using rainfall data and the assumed runoff coefficient (10%), groundwater recharge is estimated. The net availability of groundwater is estimated by either adding or deducting the previous season's balance (Table 18). There

3 To qualify to be a volunteer, the farmers have to undergo training (4 modules) and only the successful candidates are eligible to become a PHM volunteer. The rigorous training ensures that there is no dilution in technical observations. The volunteers are provided with measuring tools such as electrical water level indicators, stop watches and measuring drums (shared by a number of volunteers). The volunteers maintain a log book of the Hydrological Monitoring Records (HMR). The HMR data is also exhibited for public viewing on display boards maintained at strategic locations in the habitation. Seasonal groundwater quality measurements are carried out from public drinking water wells.

may be positive or negative water balance in each season depending on the recharge and draft. Based on the crop water requirements and the net available groundwater, crop areas are decided in a collective manner. By following local measures, the volunteers explain the area under each crop with the available groundwater. They estimate the area that can be devoted to paddy, the amount of water that can be used for paddy crop or other crops or a combination of different crops.

Table 18: A Sample of Groundwater Balance Estimates for a Few HUNs in 2008-2009

(in cubic Meters)

HU Name	No. of Habi tations	Kharif Recharge	Kharif Draft	Kharif balance (+ Or -)	Rabi Recharge	Rabi Draft	Rabi Balance (- or +)
Chinneru	18	1923040	6408000	4970881	19922151	13131920	1325550
Rallavagu	15	1785521	4255000	760671	12110183	5349920	4150503
Thundlavagu	7	1486319	4524000	2565112	11628227	7130900	959832
Peddavagu	5	646770	1240000	170896	1873654	3015560	-1762674
Lothuvagu	1	342844	582000	46692	696252	291400	161869
Chandravagu	4	507897	1020000	133397	1219209	2415680	-1727864
Buchammakonetivanka	1	244757	360000	80257	541018	1536500	-1122631
Konetivanka	3	298753	1050000	1536003	4231643	3671200	-494390
Bavanasi	12	2136940	3024300	4968380	15224395	11432080	1959941
Yerravanka	4	606641	1800000	271304	3239133	5476720	-3478769
Peddavanka	4	344320	2619000	2311120	9531133	6631520	9772

Source: APFAMGS Project report, http://www.apfamgs.org.

The estimates show that in 59 of the 63 Hydrological Units (Hus), groundwater balance is deficit. The CWB has also identified over-exploited aquifers. Water harvesting measures such as injection wells have been taken up in the over-exploited aquifers. In some areas, abandoned open wells have also been used to trap the flood flows and transfer them to the aquifers. Though there is no coercive mechanism to force the farmers to adopt the collective decisions, a survey is conducted after every season on the extent to which collective decisions were followed and discussed in the GMC. This data on actual cropping pattern is used to arrive at the actual draft. There is always a difference between the estimated and actual draft. Though individual farmer's decisions are respected, GMCs and HUNs are able to act as pressure groups to advocate change in cropping patterns, use of sustainable agricultural practices and water saving technologies in some places.

Achievements

The achievements are drawn from the self-assessment reports of the APFAMGS, and independent evaluation reports of the World Bank (nd), FAO (2008) and AFPRO

(2006), coupled with our field experience. All the physical achievements reported (Table 19) by the end of 2007 are endorsed in the evaluation studies. The figures are quite impressive as most of the HUs (559 out of 650) have created the hydrological data base and are managing (636 Community Based Institutions (CBIs)) their groundwater. In fact, the data generated is the property of the GMC and is being sold to outside agencies for the purpose of research. More than 4000 farmers are trained to read maps and more than 10000 farmers can handle hydrological equipment. It is assessed that some of the achievements have surpassed the targets (FAO, 2008). During the field visits, we have observed the farmers presenting crop water budget estimates and taking the water table measurements. However, farmers are yet to be trained on using the GIS.

Table 19: Physical Achievements of APFAMGs Programme (2007)

Indicator	Achievement
Number of farmers capable of reading maps	4322
Number of farmers capable of handling hydrological equipment	10076
Number of farmers updating Hydrological Monitoring Records (HMR)	3052
Number of GMCs using GIS	0
Number of GMCs having hydrological database	559
Number of GMCs Sharing hydrological database	559
Number of farmers adopting alternative agricultural practices/inputs	14281
Types of alternative agricultural practices promoted	80
Number of CBIs involved in groundwater management	636
Number of women on the committees of CBIs	2060
Number of women farmer volunteers	1175
Number of GMCs operating Crop Water Kiosks(CWK)	9
Number of GMCs advising farmers on crop choices based on CWB	559
Number of GMCs promoting alternative agriculture	559

Source: APFAMGS Project report, http://www.apfamgs.org.

Three hundred Farmer Water Schools (FWS)[4] have been established to train the farmers to equip them with technical and non-technical aspects of groundwater management. Hydro-Ecosystem Analysis (HESA), which is a decision-making tool for groundwater management, is being adopted and supported by recharge and discharge factors. Crop plans and management of groundwater is based on this analysis and observations. This is the same sequence used for Agro-Ecosystem Analysis in the classical Farmer Field

[4]Under the FWS 10000 farmers meet once in every 15 days through 300 water schools to understand groundwater changes in the respective area for the entire hydrological season. Based on the understanding, farmers adopt suitable modification in their agricultural practices that can lead to significant reductions in groundwater use.

Schools (FFS) approach (FAO, 2008).The focus of FWS is on the active and common farmers who can apply them directly on farm and also share them with a larger audience. The FWS has successfully created the first batch of over 10000 farmers who have already emerged as trainers to other farmers both under the project programme as well as for the government-run FFS. Such a training and adaptation has demystified hydrology, which is a hidden source, and helped farmers in understanding the resource availability and dynamics. Sharing of information across HUs resulted in evolving common strategies, limiting the depletion of groundwater table.

Some of the important achievements include reduction in groundwater pumping in a number of HUs. In 14 of the 63 HUs groundwater pumping has been reduced significantly, while in 9 other HUs the reduction was moderate. Overall, despite the reduction in pumping in number of HUs, the reduction is not significant enough to have a drainage basin-level impact. Reduced water pumping has a direct bearing on area under paddy, as paddy is water-intensive and the most preferred crop. In all, except in four HUs, the area under paddy cultivation has come down, ranging from a few acres to several hundred acres. The farmers' experience showed that they incur crop losses whenever they do not follow the collective advice due to water scarcity. Crop diversification has taken place in favour of pulses, oil seeds, fruits, vegetables, flowers, etc. Farmers try to offset the losses due to reduction in paddy by growing other high value crops. The risks associated with commercial crops such as mono-culture, reduced area under food crops, and loss in soil fertility, are also being addressed simultaneously. Water saving devices such as Sprinkler and Drip Irrigation have been introduced for crops such as groundnut, sunflower, bengal gram, chillies and horticultural crops. It is estimated that groundwater pumping was reduced by more than 8% (equivalent to 5 mcm per year) over the project area due to water saving techniques.

Shortcomings

- The methodology adopted for generating the hydrological information is not fully scientific. There is a need to link the estimation methodology to the Government of India methods of estimation.
- Provision of information alone may not be effective unless other policy issues that contradict the demand management of groundwater, viz., free power and distorted price policies that favour water-intensive crops such as paddy are corrected.
- Equity issues are not fully addressed in the management, as the fundamental issue of water rights is not addressed. It is necessary to address the issue of delinking water rights with land rights at the community level.
- Despite a systematic bottom-up approach towards sustaining the initiative, sustainability still remains a major concern in the absence of external funding and involvement of NGOs.

VI Future Directions for Policy and Research

This paper highlights three important aspects of sustainable groundwater management in AP.

- The paper establishes the increasing importance of groundwater and its management.
- The paper highlights the drawbacks of the information on groundwater presently available through official sources.
- Innovative institutional arrangements can address the information bottlenecks to a large extent, though its effectiveness in achieving the objectives calls for an integrated approach.

Hydrology is treated as a pure physical science and hydrological information is often generated and disseminated in an esoteric form with little or no effort to bring it closer to the user communities. Unlike other physical sciences, hydrology or hydrological information plays vital role in the day to day livelihoods of groundwater-dependent communities. The existing link between the scientific information and the users is very weak, serving no real purpose of helping the farming communities. Often, the information provided at a macro scale is inadequate and inappropriate to suit the micro-level situation and needs of the farmers.

The case of APFAMGS clearly brings out the great possibilities for demystifying hydrology and makes it user friendly through capacitating communities in generating scientific hydrological information at the village level. While these are found to be highly productive in terms of benefits to the user communities, sustaining and scaling up such initiatives calls for an integrated approach of combining physical and social sciences along with policy makers and development practitioners (NGOs).

The scientific community should gear up to meet the needs of groundwater users through provision of more scientific and appropriate information to the users. The estimation methodologies need improvement along with increasing the number of observation wells and rain gauge stations. Policy makers should focus on providing hydrological information at a much lower scale than it is being done presently. Appropriate scale and methods suitable for hard rock areas as well as alluvial soils need to be developed. This becomes critical in the context of climate change. Policies should move towards focusing on groundwater management rather than development. For this purpose, innovative policies are needed, involving local communities and NGOs as partners. Generation of hydrological information at the village level is quite possible through the involvement of local communities and the NGOs. The NGOs can help in the process of capacitating the communities to take up the scientific activities. Finally, an integrated policy approach (integrating all the relevant policies such as power and pricing) and delinking land and water rights are very important for ensuring equitable distribution of the common resources.

References

AFPRO (2006), "A systematic Assessment of Community based Groundwater Management Experiences in Andhra Pradesh", Action for Food Production, Field Unit 6, Hyderabad, December.

APFAMGS (2006), "Rebuilding Groundwater Dependent Economy through Managed Aquifer Recharge (MAR)", Grama Vikas Samstha, Madanapally and APFAMGS, Hyderabad, January.

Ballabh, Vishwa *et al.* (2003): "Groundwater and Agriculture Production: A Comparative Study of Eastern UP, Bihar and West Bengal", IWMITATA Water Policy Programme, Anand.

Bhatia, Bela (1992), "Lush Fields and Parched Throats, Political Economy of Groundwater in Gujarat", *Economic and Political Weekly*, December 19-26, pp. A-142 to A-170.

Brown (2005), in Pradeep Raj (2006), "Status of Ground Water in Andhra Pradesh: Availability, Use and Strategies for Management", Participatory Groundwater Management Component in AP Community Based Tank Management Project, Project Preparatory Note, I&CAD Department, GoAP, Hyderabad, August.

CGWB (2006), "Dynamic Groundwater Resources of India" (as on March 2004), Central Groundwater Board, New Delhi.

Deshpande R.S. and V. Ratna Reddy (1990), "Social Dynamics and Farmers' Society: A Case Study of Pani–Panchayat" (jointly), *Indian Journal of Agricultural Economics,* Vol. XLV, No. 3, July-September.

FAO (2008), "Evaluation of FAO Cooperation with India: Andhra Pradesh Farmer Managed Groundwater Systems (APFAMGS - GCP/IND/175/NET) Evaluation Report" http://www.apfamgs.org.

FAO (2004), "Economic Valuation of Water Resources in Agriculture: From the Sectoral to a Functional Perspective of Natural Resource Management", FAO Water Report 27, Rome.

GoAP (2003), "AP Water Vision", Mission Support Unit of AP Water Conservation Mission, Andhra Pradesh Government.

GoAP (2004), "AP Water Vision", Mission Support Unit of AP Water Conservation Mission, Andhra Pradesh Government.

GoAP (2006), "Failed Bore Well Compensation Scheme", G.O. Rt No.1099.

GoAP (2008), "Groundwater Resource Andhra Pradesh 2007", State Groundwater Department, Hyderabad, August.

GoI (1997), "Groundwater Estimation Committee Groundwater Estimation Methodology 1997", Ministry of Water Resources, Government of India.

GoI (2002), "Report on the Hard Rock Ground Water Estimation", Central Ground Water Board, Ministry of Water Resources, New Delhi.

GoI (2006), "Central Ground Water Board", Dynamic Groundwater Resources of India (as on March 2004), New Delhi.

GoI (2007), *Report of the Expert Group* on Groundwater Management and Ownership, Planning Commission, New Delhi, September.

GoI (2007), Report of the Steering Committee on Water Resources for Eleventh Five Year Plan (2007-2012), Planning Commission, May.

GoI (2009), Report of the Groundwater Resource Estimation Committee, Groundwater Resource Estimation Methodology, Ministry of Water Resources, Government of India, New Delhi.

Gunatilaka, A. (2005), "Groundwater Woes of Asia". Asian Water, January/February.

Howard, K. (2004), "Strategic Options and Priorities in Groundwater Resources: Workshop Context", Presented at the STAP-GEF Technical Review Workshop on Strategic Options and Priorities in Groundwater Resources, United Nations Educational, Scientific and Cultural Organization, 5-7 April, Paris.

IGES White Paper (nd), "Groundwater and Climate Change: No Longer the Hidden Resource", Chapter 7.

Kulkarni, Himanshu and P.S. Vijay Shankar, (2009), "Groundwater: Towards an Aquifier Management Framework", *Economic and Political Weekly*, Vol.44, No.6, February 07-February 13, pp.13-17.

Kumar, M. Dinesh (2003), "Food Security and Sustainable Agriculture in India: The Water Management Challenge", IWMI Working Paper 60. Colombo: IWMI.

Kumar, M. Dinesh, L. Singhal, PabitraRath (2004): "Roof Water Harvesting for Domestic Water", *Economic and Political Weekly*, July 31.

Kumar M. Dinesh, Ankit Patel, R. Ravindranath, O.P. Singh(2008), "Chasing a Mirage: Water Harvesting and Artificial Recharge in Naturally Water-Scarce Regions", *EPW*, August 30.

Llamas, R., and E. Custodio (eds.) (2003), *Intensive use of Groundwater—Challenges and Opportunities*, Leiden, Netherlands: Balkema.

Moench, Marcus (1992) "Chasing the Water Table: Equity and Sustainability in Groundwater Management", *Economic and Political Weekly*, 27(51-52):171-177.

Moench, Marcus (2000), "India's Groundwater Challenge", downloaded from http://www.india-seminar.com/2000/486/486%/20moench.htm on 16th June, 2006.

Morris, B.L., A.R.L. Lawrence, P.J.C. Chilton, B. Adam, R.C. Calow and B.A Klinck (2003), "Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem and Options for Management", Early Warning and Assessment Report Series, United Nations Environment Programme, Nairobi, Kenya.

Mukherjee, Aditi and Tushaar Shah (2005), "Groundwater Socio-Ecology and Governance: A Review of Institutions and Policies in Selected Countries", *Hydrogeology Journal*, 13, 1: 328-345.

Mukherji, A. and Shah, T. (nd), "Groundwater Governance in South Asia: Governing a Colossal Anarchy", Water Policy Research Highlight No. 13 IWMI-TATA, Vallabh Visyanagar, P. 2.

Nagaraj, N. and M.G. Chandrakanth (1997): "Intra and Inter-Generational Equity Effects of Irrigation Well Failures: Farmers in Hardrock Areas of India", *Economic and Political Weekly*, 32 (13): A-41 to A-44.

Narasimhan (2008), "Groundwater Management and Ownership", *Economic and Political Weekly*, February 16, pp. 21-27.

Pant (1992), *New Trends in Indian Irrigation – Commercialisation of Groundwater*, Ashish Publishing House, New Delhi.

Pant Niranjan (2004), "Control of and Access to Groundwater in UP", *Economic and Political Weekly*, June 25.

Reddy V. Ratna (2002), "Environmental Degradation: Market, Policy and Institutional Failure (A Case of Water Resources in Andhra Pradesh)", Funded by The World Bank Aided "India: Environmental Management Capacity Building" Technical Assistance Project, Indira Gandhi Institute of Development Research, Mumbai, March.

Reddy V. Ratna (2003), "Costs of Resource Degradation Externalities: A Study of Groundwater Depletion in Andhra Pradesh", Working Paper No. 49, Centre for Economic and Social Studies, Hyderabad, March.

Reddy V. Ratna (2005), "Costs of Resource Depletion Externalities: A Study of Groundwater Overexploitation in Andhra Pradesh, India", *Environment and Development Economics* (Cambridge), Vol. 10, Part IV, August.

Reddy V. Ratna (2004), "Managing Water Resources in India: A Synoptic Review", *Journal of Social and Economic Development*, Vol.6, No. 2, July-December.

Reddy V. Ratna and Bhagirath Behra (2009), "The Economic and Ecological Impacts of Tank Restoration in South India" (jointly), *European Journal of Development Research*, Vol. 21, February.

Reddy V. Ratna, M.Gopinath Reddy and John Soussan (2010), *Political Economy of Watershed Management: Politics, Institutions, Implementation and Livelihoods*, Rawat Publications, Jaipur.

Scott, C.A. and T. Shah (2004), "Groundwater Overdraft Reduction through Agricultural Energy Policy: Insights from India and Mexico", *International Journal of Water Resources Development*, 20(2): 149-164.

Shah, T., A. DebRoy, A.S. Qureshi, and J. Wang, (2003), "Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence", *Natural Resources Forum* 27 (2): 130-40.

Shah, Tushaar (1991), "Efficiency and Equity Impacts of Groundwater Markets: A Review of Issues, Evidence and Policies", Research Paper, Institute of Rural Management, Vol. 37, No. 8.

Shaheen and Shiyani (2005), "Equity Redistribution Groundwater Bore-wells in North Gujarat", *Economic and Political Weekly*, January 22.

Singh Katar (1995), "Cooperative Property Rights as Instruments for Managing", Monograph, VIKSAT-National Heritage Institute, Ahmadabad: VIKSAT.

Swallow, B., Garritty, D.P. and van Noordwijk, M. (2001), "The Effect of Scales, Flows and Filters on Property Rights and Collective Action in Watershed Management", Capri Working Paper No. 16, EFPRI, Washington D.C.

UN (1960), *Large-Scale Groundwater Development*. Water Resources Development Centre, New York.

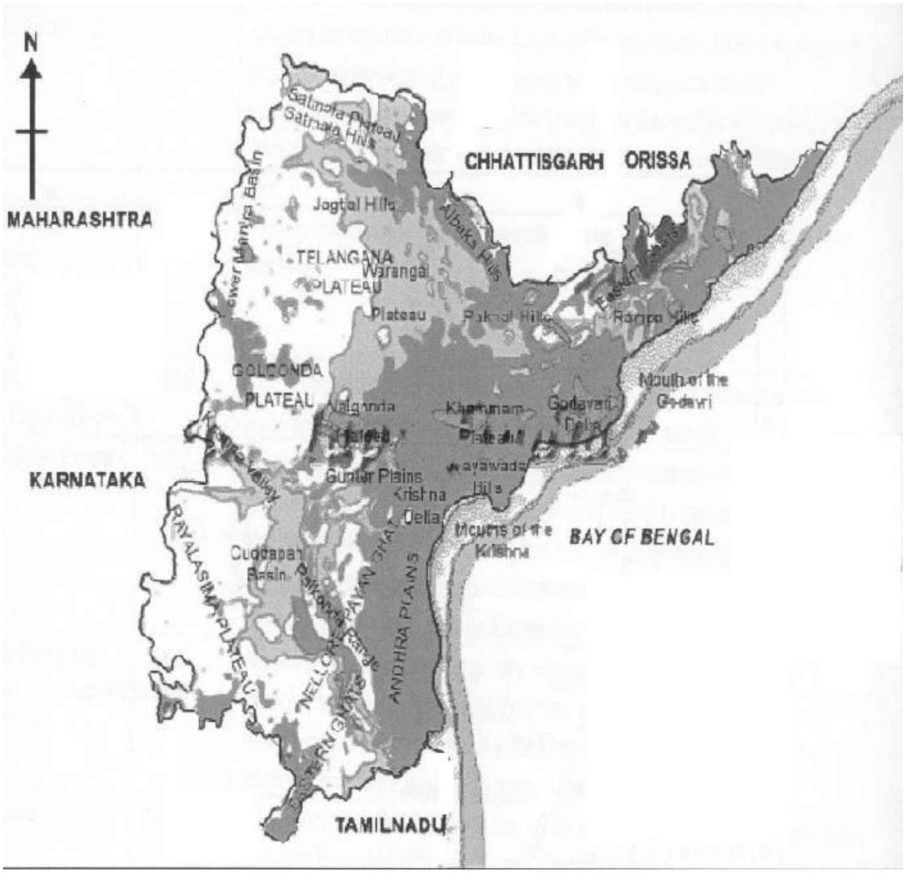
van Halsema, G.E. (2002), "Trial and Re-trial: The Evolution of Irrigation Modernisation in NWFP, Pakistan", PhD diss., Wageningen University, Department of Water Resources, Netherlands.

Winter, T.C., J.W. Harvey, O.L. Franke, and W.M. Alley (1998), *Ground Water and Surface Water: A Single Resource*, U.S. Geological Survey Circular 1139, U.S. Department of the Interior, U.S. Geological Survey, Denver, Colo.

World Bank (nd), "Deep Wells and Prudence: Towards Pragmatic Action for Addressing Groundwater Overexploitation in India", APFAMGS, http://www.apfamgs.org.

Annexure

Figure 1: Physiographical Map of Andhra Pradesh

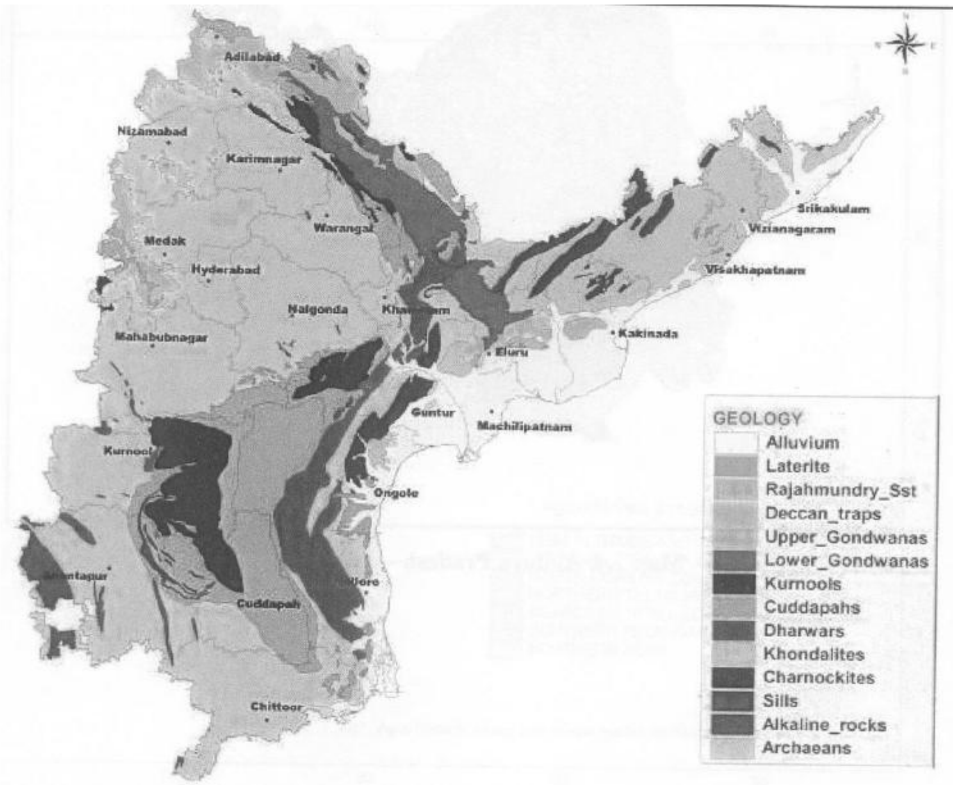


Source: Department of Ground Water, GoAP, Hyderabad.

Figure 2 – Agro-Climatic Zones of Andhra Pradesh

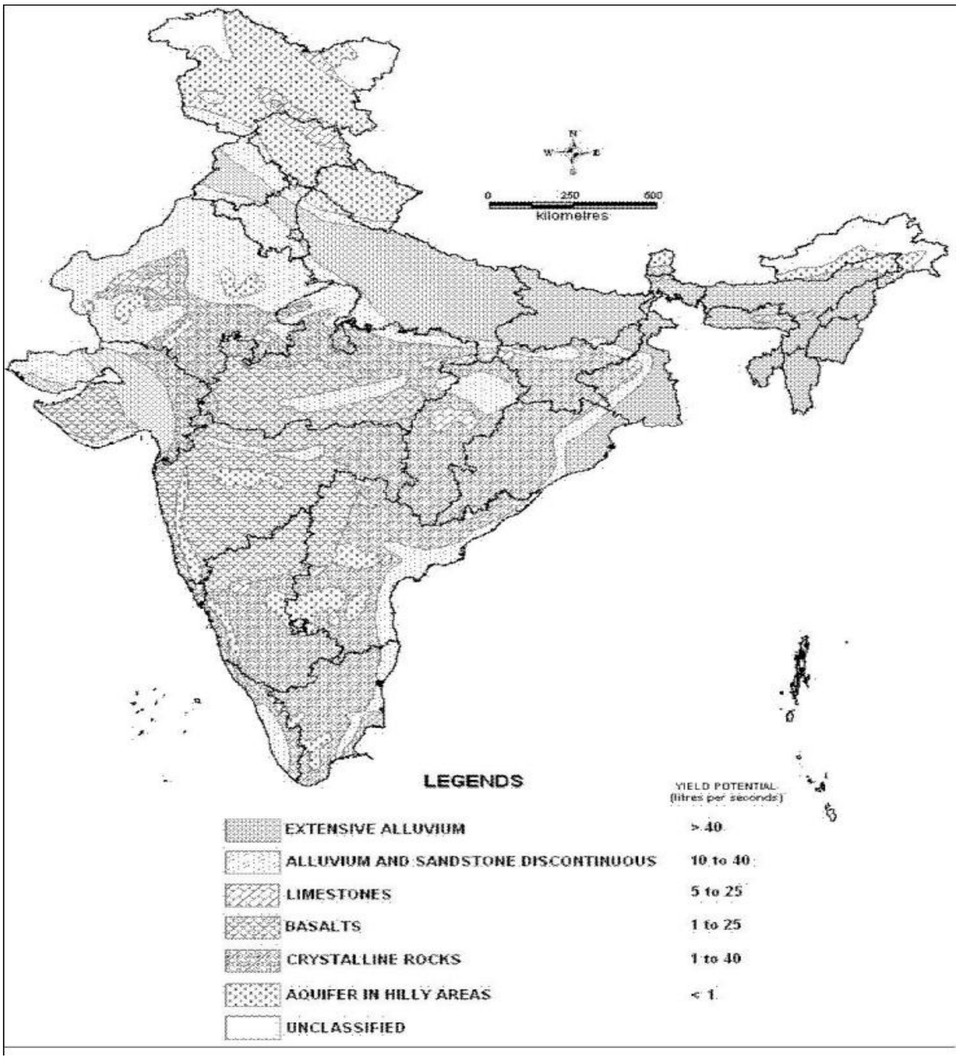
Source: Acharya N G Ranga Agricultural University (2008), Annual Report 2007-08, Hyderabad

Figure 3: Geological Map of Andhra Pradesh



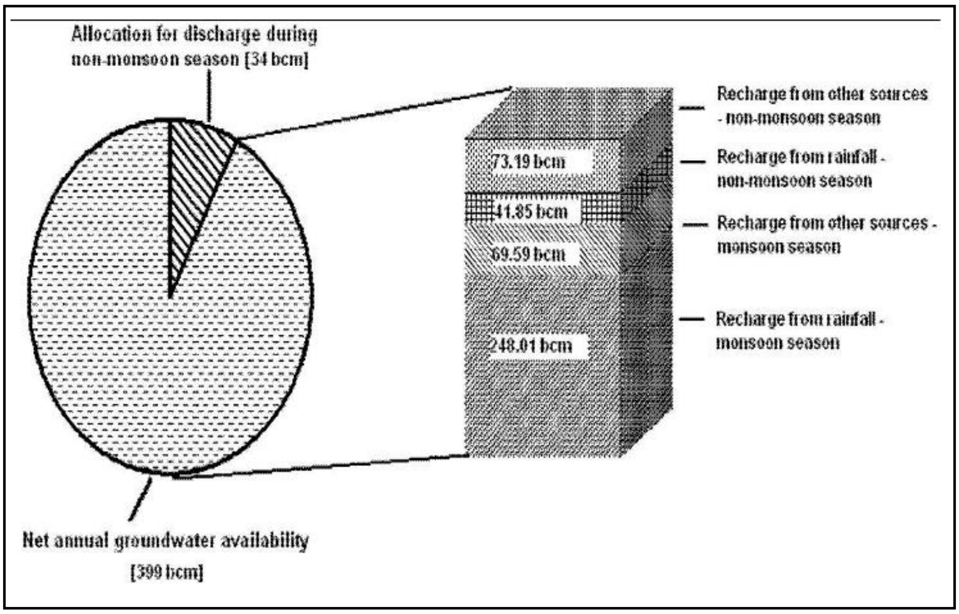
Source: GoAP (2008), Groundwater Resource Andhra Pradesh 2007, Vol-I, Department of Ground Water, August. Hyderabad.

Figure 4: Major Aquifer Systems of India



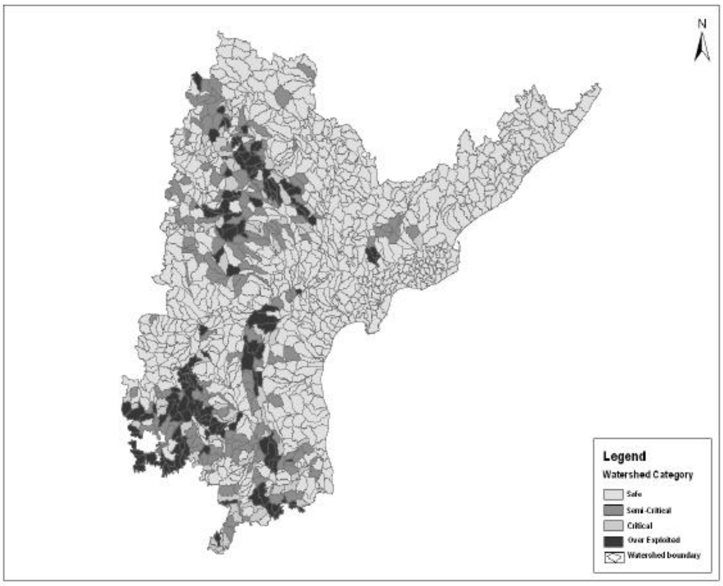
Source: GoI, CGWB, Ministry of Water Resources of India, New Delhi.

Figure 5: Annual Replenishable Groundwater Resources



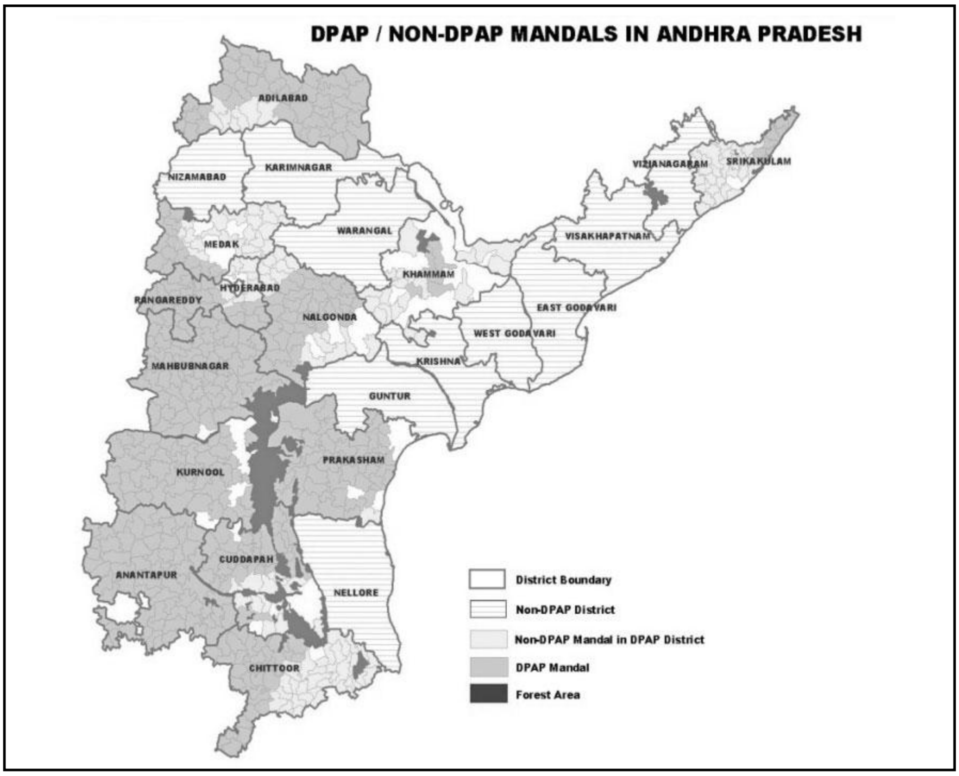
Source: GoI, CGWB, Ministry of Water Resources of India, New Delhi.

Figure 6: Status of Groundwater Development in Andhra Pradesh (2007)



Source: GoAP (2008), Groundwater Resource Andhra Pradesh 2007, Vol-I, Department of Ground Water, August. Hyderabad

Figure 7: DPAP and Non-DPAP Districts of Andhra Pradesh



Source: Commissioner of Rural Department (Watersheds), GoAP, Hyderabad.

Table 1: Descriptive Statistics of Selected Variables

(N=22)

Variables	1985		1993		2002		2004		2007	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A ARF (in mm)	731.14	194.02	814.36	150.17	919.05	158.79	744.95	180.67	861.12	270.23
I I	126.61	19.18	127.62	18.99	128.97	19.81	127.91	19.50	133.22	20.52
CI	118.02	14.73	125.31	19.68	124.77	19.89	124.37	19.28	129.01	21.95
HDI	—	—	0.39	0.07	0.62	0.10	0.52	0.07	0.52	0.07
% Persons BPL	55.09	15.10	40.82	11.93	34.19	12.93	31.33	13.72	28.60	14.73
PCI (in Rs.)	—	—	7319.00	1264.49	9934.50	1697.68	19167	4314.19	22845.27	4787.88
Literacy Levels	27.69	6.37	41.64	7.25	58.69	7.00	58.69	7	58.69	7
Sugarcane (in ha)	7626.77	9644.85	13402.0	16473.2	16374.9	21927.4	16066.2	19977.9	19924.82	22955.04
Groundnut (in ha)	15019.27	12716.8	19475.7	15804.1	13631.0	13592.5	11634.9	12046.3	11276.77	12230.58
No. of Dug Wells	2117.91	1933.52	937.36	896.06	513.05	696.95	546.77	1130.51	161.09	353.18
No. of Tube wells	614.09	556.87	1302.77	1210.13	1291.23	1147.41	2114.59	2354.85	594.50	651.87
No. of Agrl. Service Connections	2011	1869.67	4644.36	2718.03	5374	3475.52	2943.64	2110.43	3953.50	2239.61
No. of WSD	—	—	—	—	303.50	229.04	435.36	358.39	503.77	403.62
No. of Tanks	3590.50	2770.95	3632.50	2810.64	3747.41	2786.43	3747.41	2786.43	2717.68	2341.15
NIA Canals (in ha)	81540.41	92234.2	75409.8	84299.5	74972.1	81089.5	61180.8	76910.4	73761.55	80993.86

Table 2: Factors Influencing Groundwater Development in Command and Non-Command Areas (1985)

Variable	Command		Non-Command		Overall	
	Coefficient	VIF	Coefficient	VIF	Coefficient	VIF
Constant	-33.18 (-2.96)*		-50.741 (-2.033)**		-55.357 (-2.587)*	
I I	0.096 (1.84)**	1.105	—	—	—	—
No. of Tube Wells	0.002 (1.27)	1.120	—	—	—	—
% of BPL Population	0.161 (2.14)*	1.548	—	—	0.399 (2.257)*	1.572
Literacy Levels	0.564 (2.868)*	1.986	2.177 (3.021)*	1.606	1.379 (3.000)*	1.995
No. of Agrl. Service Connections	0.002 (2.412)*	1.491	0.015 (5.361)*	1.683	0.009 (5.664)*	1.490
No. of Tanks	--	--	0.004 (2.184)*	1.373	0.001 (1.094)	1.456
Groundnut	--	--	?0.001 (?1.762)**	1.233	--	--
R2 (R Bar)	0.57 (0.41) N=22		0.73 (0.66) N=22		0.74 (0.67) N=22	

Table 3: Factors Influencing Groundwater Development in Command and Non-Command Areas (1993)

Variable	Command		Non-Command		Overall	
	Coefficient	VIF	Coefficient	VIF	Coefficient	VIF
Constant	-15.76 (-1.14)	—	-15.77 (-1.14)	—	-15.63 (-1.132)	—
II	0.186(1.790)**	1.559	0.185(1.776)**	1.559	0.184 (1.775)**	1.559
No. of Dug wells	0.003 (1.345)	1.115	0.003(1.342)	1.115	0.003(1.346)	1.115
No. of Tube wells	0.002(1.217)	1.521	0.002(1.224)	1.521	0.002(1.218)	1.521
HDI	47.342(1.919)**	1.348	47.738(1.931)**	1.348	47.434(1.920)**	1.348
NIA Canals	-0.000 (-3.930)*	1.492	-0.000 (-3.926)*	1.492	-0.000 (-3.931)*	1.492
R^2 (R Bar)	0.65 (0.55) N=22		0.65 (0.55) N=22		0.65 (0.55) N=22	

Table 4: Factors Influencing Groundwater Development in Command and Non-Command Areas (2002)

Variable	Command		Non-Command		Overall	
	Coefficient	VIF	Coefficient	VIF	Coefficient	VIF
Constant	-4.227 (-0.178)		-72.546 (-1.693)	—	-41.885 (-1.097)	—
Actual Annual Rainfall (AARF)	—	—	—	—	-0.040 (-1.775)**	1.491
II	-0.061 (-0.474)	1.544	0.617 (2.512)*	1.416	—	—
No. of Dug Wells	-0.006 (-1.859)**	1.361	-0.003 (-0.527)	1.177	—	—
No. of Tube wells	0.008 (2.466)*	1.916	0.011 (2.572)*	1.547	—	—
Crop Intensity	—	—	—	—	.479 (2.390)*	1.841
HDI	24.605 (0.795)	1.875	51.600 (1.144)	1.232	110.886 (3.377)*	1.265
% of BPL Pop.	0.675 (3.320)*	1.523	0.178 (0.489)	1.325	—	—
No. of Watersheds	-0.038 (-2.890)*	2.026	-0.006 (-0.252)	2.026	—	—
NIA Canals	—	—	—	—	0.000 (-4.792)*	1.818
Groundnut	—	—	—	—	0.001 (2.409)*	1.870
R2 (R Bar)	0.60 (0.40) N=22		0.64 (0.49) N=22		0.76 (0.68) N=22	

Table 5: Factors Influencing Groundwater Development in Command and Non-Command Areas (2004)

Variable	Command		Non-Command		Overall	
	Coefficient	VIF	Coefficient	VIF	Coefficient	VIF
Constant	36.760 (2.091)**	—	177.744 (6.261)*	—	35.896 (1.435)	—
AARF	—	—	-0.115 (-4.502)*	1.727	-0.040 (-2.275)*	1.219
II	—	—	—	—	0.482 (3.236)*	1.023
No. of Tube Wells	0.007 (2.245)*	1.930	0.004 (2.581)*	1.356	0.003 (2.366)*	1.143
PCI (constant prices)	0.001 (1.190)	1.286	0.000 (-0.322)	1.238	—	—
No. of Watersheds	-0.034 (-3.090)*	2.114	-0.038 (-2.667)*	2.132	—	—
No. of Tanks	-0.001 (-0.576)	1.379	-0.003 (-2.262)*	1.362	-0.003 (-2.457)*	1.291
NIA Canals	0.000 (-5.342)*	1.512	0.000 (-0.881)	1.444	0.000 (-4.895)*	1.361
R^2 (R Bar)	0.71 (0.60) N=22		0.71 (0.60) N=22		0.81 (0.75) N=22	

Table 6: Factors Influencing Groundwater Development in Command and Non-Command Areas (2007)

Variable	Command		Non-Command		Overall	
	Coefficient	VIF	Coefficient	VIF	Coefficient	VIF
Constant	161.492 (3.341)*		-38.909 (-1.047)	—	67.707 (2.600)*	—
AARF	—	—	-.074 (-4.982)	1.603	-0.062 (-4.226)*	1.571
II	—	—	—	—	0.394 (2.425)*	1.115
No. of Dug Wells	0.007 (.609)	1.19	—	—	—	—
No. of Tube Wells	—	—	—	—	-0.011 (-1.774)**	1.515
Crop Intensity	—	—	0.735 (3.500)*	2.112	—	—
HDI	-192.377 (-2.5)*	2.05	—	—	—	—
PCI	—	—	—	—	0.000 (-0.076)	1.104
Literacy Levels	—	—	1.173 (2.207)*	1.376	—	—
No. of Agrl. Service Connections	—	—	0.003 (1.799)**	1.151	—	—
No. of Watersheds	-0.029 (-2.316)*	2.12	—	—	—	—
No. of Tanks	-0.006 (-2.823)*	1.76	—	—	—	—
NIA Canals	0.000 (-1.909)**	1.66	0.000 (-3.198)*	1.790	0.000 (-4.556)*	1.095
R^2 (R Bar)	0.49 (0.34) N=22		0.74 (0.67) N=22		0.74 (0.67) N= 22	

Table 7: Factors Influencing Groundwater Development in DPAP and Non-DPAP Regions (1985)

Variable	DPAP			Non-DPAP		
	Coefficient	t	VIF	Coefficient	t	VIF
Constant	61.999	3.499		-30.675	-1.551	
No. of Dug Wells	—	—	—	0.006*	7.498	1.069
II	—	—	—	0.225	1.961	1.085
AARF	-0.049**	-1.937	1.062	0.025**	2.230	1.112
No. of Agrl. Service Connections	0.004**	2.083	1.049	—	—	—
NIA under Project Canals	0.000*	-2.496	1.034	—	—	—
R^2 (R Bar)	0.65 (0.5) N= 12			0.92 (0.87) N= 10		

Table 8: Factors Influencing Groundwater Development in DPAP and Non-DPAP Regions (1993)

Variable	DPAP			Non-DPAP		
	Coefficient	t	VIF	Coefficient	t	VIF
Constant	-15.249	-0.732		-0.495	-0.056	
CI	0.462*	2.671	1.388	—	—	—
AARF	-0.032*	-3.328	1.113	—	—	—
NIA Canals	0.000*	-4.838	1.394	—	—	—
Literacy Level	0.594*	2.502	1.131	—	—	—
No. of Agrl. Service Connections	—	—	—	0.003*	2.892	1.245
% of Population BPL	—	—	—	0.392	1.501	1.245
R Square	0.85 (0.77) N= 12			0.72 (0.64) N= 10		

Table 9: Factors Influencing Groundwater Development in DPAP and Non-DPAP Regions (2002)

Variable	DPAP			Non-DPAP		
	Coefficient	t	VIF	Coefficient	t	VIF
Constant	-89.807	-1.209		-151.371	-3.033	
NIA Canals	-0.001*	-5.294	1.375	—	—	—
% of Population BPL	-0.558	-1.433	1.627	1.317*	4.953	1.321
CI	1.446*	2.307	1.208	—	—	—
Coverage of WSDP	0.060**	2.236	1.439	—	—	—
Actual Annual Rainfall	—	—	—	0.115**	2.225	1.791
No. of Tube wells	—	—	—	0.010**	2.078	1.409
II	—	—	—	0.168	1.386	1.249
R^2	0.82 (0.71) N= 12			0.91 (0.84) N= 10		

Table 10: Factors Influencing Groundwater Development in DPAP and Non-DPAP Regions (2004)

Variable	DPAP			Non-DPAP		
	Coefficient	**t**	**VIF**	**Coefficient**	**t**	**VIF**
Constant	138.847	2.013		137.115	2.465	
AARF	-0.067*	-3.236	1.418	—	—	—
II	0.553	1.618	1.621	0.350**	2.158	1.032
HPI (2001)	-195.221*	-2.811	1.405	-198.943**	-2.140	1.497
NIA Canals	0.000**	-1.939	1.438	0.000*	-3.506	1.665
PCI	—	—	—	-0.001	-1.714	1.196
R^2	0.90 (0.84) N= 12			0.84 (0.72) N= 10		

Table 11: Factors Influencing Groundwater Development in DPAP and Non-DPAP Regions (2007)

Variable	DPAP			Non-DPAP		
	Coefficient	**t**	**VIF**	**Coefficient**	**t**	**VIF**
Constant	129.822	6.663		-3.262	-0.130	
AARF	-0.055*	-3.045	1.211	—	—	—
No. of Agrl. Service Connections	-0.005**	-1.964	1.212	0.004*	2.787	1.002
NIA Canals	0.000*	-3.241	1.166	0.000*	-3.274	1.001
Irrigation Intensity	—	—	—	0.263	1.586	1.001
R^2	0.76 (0.67) N= 12			0.79 (0.68) N= 10		