For Restricted Circulation

Occasional Paper
No. 4-0211

GROUNDWATER MANAGEMENT IN ANDHRA PRADESH: Time to Address Real Issues

M. Dinesh Kumar, MVK Sivamohan, V. Niranjan, Nitin Bassi

FEBRUARY - 2011

INSTITUTE FOR RESOURCE ANALYSIS AND POLICY
202, Riviera, Dwarakapuri Colony, Punjagutta, Hyderabad - 500 082
Tel: 91-40-4261 7392 E-mail: info@irapindia.org www.irapindia.org

GROUNDWATER MANAGEMENT IN ANDHRA PRADESH:
Time to Address Real Issues

M. Dinesh Kumar, MVK Sivamohan, V. Niranjan, Nitin Bassi

When the well is dry, we learn the worth of water: Benjamin Franklin

Abstract

With 49% of the total irrigation from groundwater, the state of Andhra Pradesh accounts for 5.3 per cent of the net groundwater irrigated area in the country. While the state remains as one of the largest exporters of rice, with paddy accounting for nearly 70 per cent of the state's total irrigated area, groundwater depletion poses serious challenges to not only the agricultural production and rural livelihoods, but also to the nation's food security.

The paper shows that the assessment of groundwater over-exploitation based on simplistic considerations of aggregate abstraction and recharge provide highly misleading outcomes. The gravity of the problems can be gauged from the extent of well failures, sharp decline in average area irrigated by wells, and increase in energy consumption for irrigation. The adverse affects of groundwater intensive use on tank irrigation also needs due attention. Further, the paper argues that ideas to improve groundwater management in the state such as promotion of drip systems, replacement of paddy by dry land crops, rainwater harvesting, community management of groundwater, and rationing of power supply in the farm sector are shallow, not based on any scientific consideration of the key physical, socio-economic and institutional parameters that determine the success or effectiveness of these interventions.

There is scant appreciation of the way irrigated paddy influences groundwater balance. The role of drip irrigation in changing agricultural water demand is often over-stated, without proper consideration to the conditions under which it becomes the "best -bet technology". The debate on the scope of rainwater harvesting and artificial recharge often ignores the fact that the regions facing groundwater depletion do not have surplus water. Pricing of electricity in the farm sector appears to be the only option the state is left with to tackle the multiple problems of wasteful expenditure on well drilling, and inefficient energy and water use. In the long run, establishing property water rights in groundwater might be a viable option, if the opportunity cost of not having them is considered.

Introduction

Andhra Pradesh is one of the most important agrarian states in the country. Agriculture accounts for nearly 25 per cent of the state's GDP. Nearly 70 per cent of the population is dependent on agriculture for livelihoods (Amarasinghe et al., 2007). Andhra Pradesh is also

[1] Executive Director, Principal Consultant, Research Officer and Senior Researcher, Institute for Resource Analysis and Policy, Panjagutta, Hyderabad-500082. Email: dinesh@irapindia.org/ dineshcgiar@gmail.com.

the "ice bowl" of the country. But, the state lags behind other peninsular states such as Karnataka and Tamil Nadu in terms of human development and economic growth. The state's gross cropped area is 7.14 per cent of the gross cropped area of the country.

Andhra Pradesh has one of the largest irrigated areas. With a gross irrigated area of 6.28 m. ha, the state accounts for nearly 7.3 per cent of the total irrigation in the country. Groundwater is the major source of irrigation in the state, with nearly 49 per cent of the net irrigation is from wells and tube wells (Source: based on Reddy, 2007; Amarasinghe et al., 2007). The rest of the irrigation is from sources such as canals, tanks and other sources. The state is mostly underlain by hard rock aquifers, with very poor storage and yield potential. Most parts of the state do not provide a favourable environment for intensive use of groundwater resources. Yet, limited access to water from surface irrigation systems such as reservoir and canal-based systems and tanks, makes farmers resort to well irrigation through open wells.

Energisation of wells was made possible through rural electrification and subsidized and free power given to farmers. This triggered exponential growth in well irrigation during the 80s through mid 90s. Along with this, the negative effects of intensive groundwater use also surfaced with drops in groundwater levels, drying up of open wells and seasonal and permanent failures of shallow and deep bore wells. These ill effects forced development activists, academia and policy makers alike to raise alarm bells. Suggestions made over the past 10-15 years to tackle groundwater depletion problems and to sustain groundwater irrigation for socio-economic development largely focused on community regulation of groundwater use at the village level; electricity metering and energy pricing; shift in cropping pattern, with replacement of irrigated paddy by dry land crops; watershed management and artificial groundwater recharge; and large-scale adoption of micro irrigation systems, and increased utilization of groundwater in canal command areas.

But, a close look at the growing literature on the topic of water management in India shows that these management solutions are not based on scientific consideration of the true factors that determine the technical feasibility and socio-economic viability of these solution, but instead are run-of the mill ideas based on popular perceptions. In this paper, a critical assessment of the status of groundwater development in the state is made at the outset, from a multi-disciplinary perspective. The key factors that would greatly influence the success and failure of various water management interventions are described; and new options for management based on the macro realities of the hydrology, geo-hydrology, and the socio-economic and policy environment are explored.

Groundwater Development in Andhra Pradesh: How Far the Estimates Reliable?

Scholars in the past had argued that assessment of groundwater over-exploitation should involve complex hydrology, hydrodynamics, geological, economic, social and ethical considerations (Custodio, 2000; Kumar et al., 2001). Kumar et al. (2001) by using the illustrative case study of Sabarmati river basin in Gujarat showed how using such complex consideration would provide an altogether different picture of groundwater exploitation from what the official estimates generally provide. Case studies of many Indian states show that the problems of over-exploitation in India are far more serious than what official estimates project. According to them it fails to incorporate the complex physical and socio-economic factors that actually determine the degree of over-exploitation of aquifers (Kumar and Singh, 2008).

The only assessments of groundwater development in Andhra Pradesh are the official estimates of the central groundwater board and state minor irrigation departments. These estimates are based on a simplistic consideration of only the 'recharge' and 'abstraction'. The recharge is the net of recharge from rainfall, percolation from natural and artificial water bodies and irrigation return flows from both well irrigation and surface irrigation. In fact, the return flow coefficient for paddy is assumed to be 0.60 (APGWD, 1977 as cited in Marechal et al., 2003). This means that of the total renewable groundwater recharge estimated for AP, a significant chunk would come from irrigated paddy fields. The abstraction estimates are based on norms of the average annual groundwater pumping by wells and bore wells.

As per the estimates, 9 per cent of the blocks in the state are over-exploited. Six per cent are in 'critical stage' with the average annual abstraction in the range of 90-100 per cent of the average annual recharge. Nearly 15 per cent of the blocks are in 'semi critical' category. Hence, as per the estimates, nearly 30 per cent of the assessment blocks are facing over-development problems. Figure 1 shows the stage of groundwater development in Andhra Pradesh at the block level.

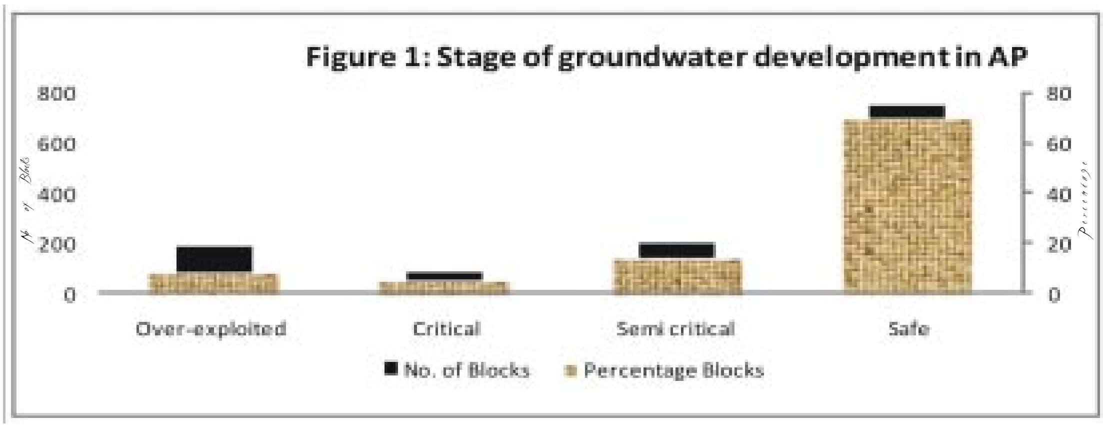


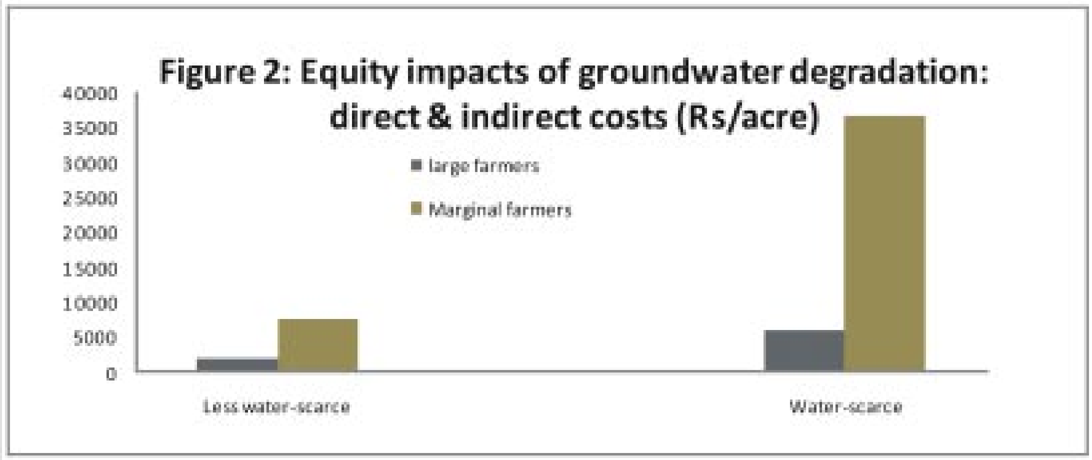
Figure 1: Stage of groundwater development in AP

The immediate reaction to this problem of increasing groundwater imbalance and "over-development" is reduction of groundwater abstraction and augmentation of the recharge through water harvesting and artificial recharge. But, no systematic understanding is developed about the real causes of the groundwater imbalance. As is evident from some of the recent research, as part of the problem stems from failure in estimating the actual abstraction watershed or mandal wise and recharge. This reduces the ability to foresee the various components of groundwater balance in the hydrological units under consideration, and fix the real "malice". As Kumar and Singh (2008) points out, in many watersheds of hard rock regions of central and peninsular India, the outflows from groundwater to the surface streams are very significant.

This component, for the non-monsoon season, is not considered in the groundwater estimation (Kumar and Singh, 2008). The extent to which this can influence the groundwater recharge and abstraction estimates depends on the scale at which assessments are carried out. Smaller the unit, higher will be the error it can induce, as outflows from one watershed can become inflows for other watershed. This phenomenon perhaps explains why in spite of large-scale problems of well failures reported from rural areas of the state, they are not reflected in the official estimates of groundwater balance.

This lack of ability to estimate some of these important components of groundwater balance in some regions, leads to under-estimation of groundwater over-exploitation as the outflows from the system always get under-estimated (Kumar and Singh, 2008). This was illustrated with the example of Narmada river basin in MP, where estimates of the stage of groundwater development continues to show positive balance in groundwater, while in many districts well failure and reduction in well yields is rampant. As noted by them, a significant percentage of open wells (17.3%) in AP had failed by 2000-01 (Kumar and Singh, 2008), though the level of groundwater development in the state was only 45% even as per 2005 estimates (GOI, 2005). The magnitude of the problems of over-exploitation is also glaring from the fact that the net area irrigated by open wells has been drastically and consistently declining in the state from 1.03 m. ha to 0.616 m. ha from 1998-99 to 2005—06, the year for which data are available (source: GOAP, 2007 as shown in Amarasinghe et al., 2007). With the open wells fast drying up, the farmers resorted to drilling deep bore wells. Thus there was a consequent increase in well irrigated area in the state.

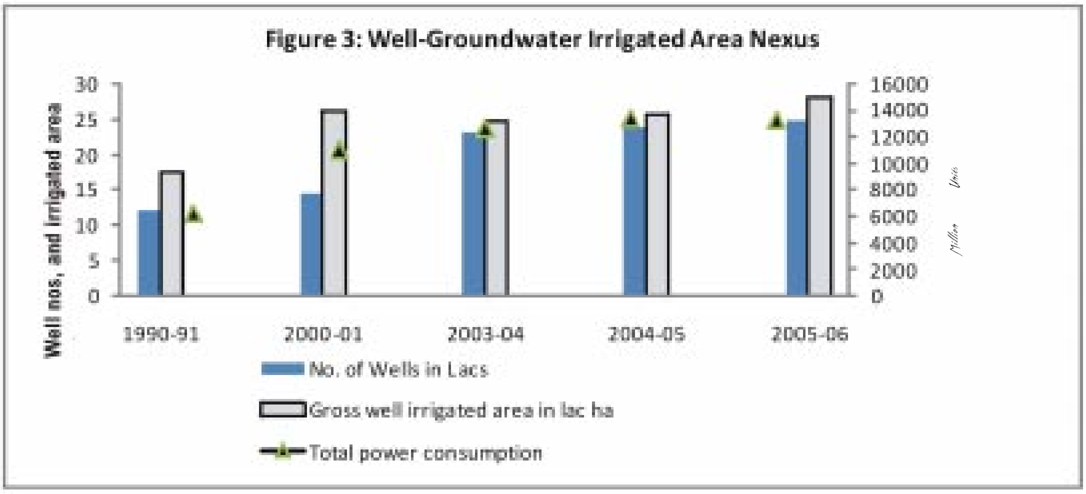
Depletion has serious negative impacts on access equity in groundwater. The small and marginal farmers bear much higher cost of resource depletion both in direct and indirect terms. They have to incur as much cost for drilling wells to access groundwater as the large farmers, but the area brought under irrigation remains much smaller. A study carried out in three villages of AP showed that the cost per acre of irrigation was much higher for small and marginal farmers, as compared to large farmers. The differences widened with increase in magnitude of water scarcity. Further, both direct and indirect cost of groundwater degradation (due to well failure, and decline in crop yield, respectively) was estimated to be very high in the water scarce village, with much higher cost being borne by the small and marginal farmers, as compared to large farmers (source: based on Reddy, 2003: Table 9 & 10, pp23).



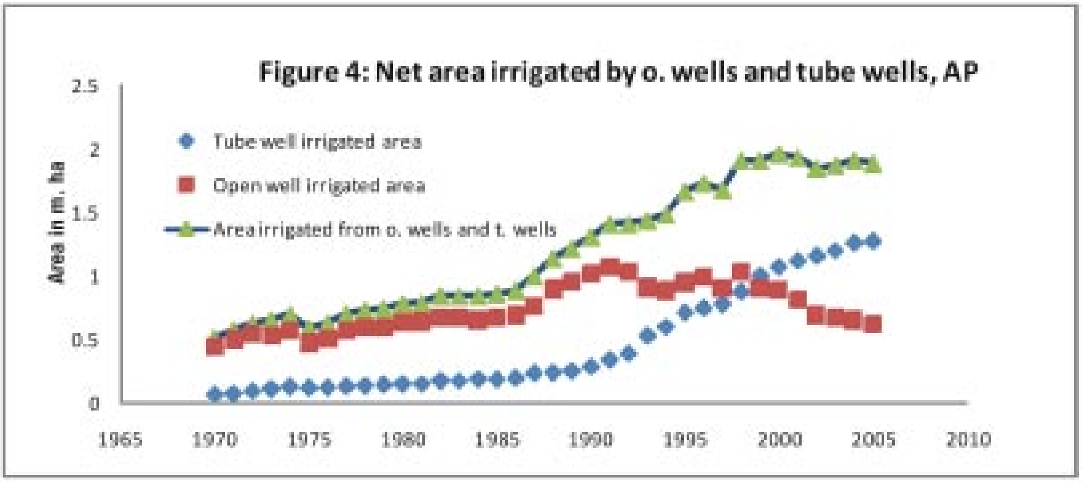
Can Groundwater Irrigation in Andhra Pradesh Grow in Future?

The aggregate statistics on groundwater development shows that there are large areas in the state, particularly canal command areas, which have abundant groundwater resources that are under-utilized (Jain, 2008). It is viewed that well irrigation in Andhra Pradesh is poised to expand further, with negative outcomes for tank irrigated area. Such predictions were based on the data on irrigated area from groundwater. But, such views shun real examination of the historical growth of groundwater irrigation in consonence with the growth in well numbers.

The data presented in Figure 3 (source: based on data provided in Jain, 2008) shows that the gross well irrigated areas were in the state are peaked in 2000-01. But, the 2003-4 data show that the irrigated area dropped by nearly 1.6lac ha from the highest figure recorded in 2000-01. There has been only a minor growth in gross irrigated area, with the highest figure recorded in 2005-06. But, what is interesting is that this had no correlation with the growth in number of wells, unlike what many scholars contended in the past. There were only



14.48lac wells in the state in 2000-01, but, all put together irrigated a gross area of 26.18lac ha. The average area irrigated by a well was 1.8 ha. But, this declined to a record low of 1.07 ha in 2003-04, with the growth in number of wells to tune of 8.62lac, not the growth irrigated area. This is a common phenomenon occurring as a result of well interference in hard rock areas. With increase in number of wells, the influence area of a wells increase and the available groundwater gets distributed among larger number of wells (Kumar, 2007). The average area irrigated by a well recorded a minor improvement in 2005-06 (1.12ha). This could be attributed to factors such as increase in recharge from rainfall, change in cropping pattern, and increase in groundwater pumping in command areas, resulting from reduced surface water release from canals for irrigation.



The figures show that by 2000-01, the state had optimum number of wells, i.e., 14.28lac to provide maximum irrigation. The only apparent benefit which is achieved through increase in number of wells is distributional equity with more farmers getting direct access to groundwater for irrigation. It is not to say that distributional equity is not an important concern in irrigation. In fact, most of the farmers who are late entrants in well irrigation are small and marginal farmers. With such high density of wells in hard rock area, the economic efficiency of groundwater abstraction becomes extremely low. This is evident from three important facts: 1] the rate of well failures is becoming alarming; 2] the area irrigated by a well has reduced to 1.07ha, down by more than 40% from the highest figure of 1.8lac ha experienced in 2000-01; 3] the power consumption for irrigating a unit area with groundwater had increased, from 3569.0 KWhr in 1990-91 to 4222.7 in 2000-01, and 5225.9 KWhr in 2003-04. Most of this increase can also be attributed to replacement of diesel engines, or energisation of manually operated wells. But, one would expect that such process of electrification of wells had taken place by the time the groundwater irrigated area touched almost the peak (i.e., in 2000-01). Therefore, it is safe to conclude that the increase in energy requirement for groundwater pumping after 2000-01 was because of increase in well numbers resulting from fast draw downs in wells due to the phenomenon of well interference.

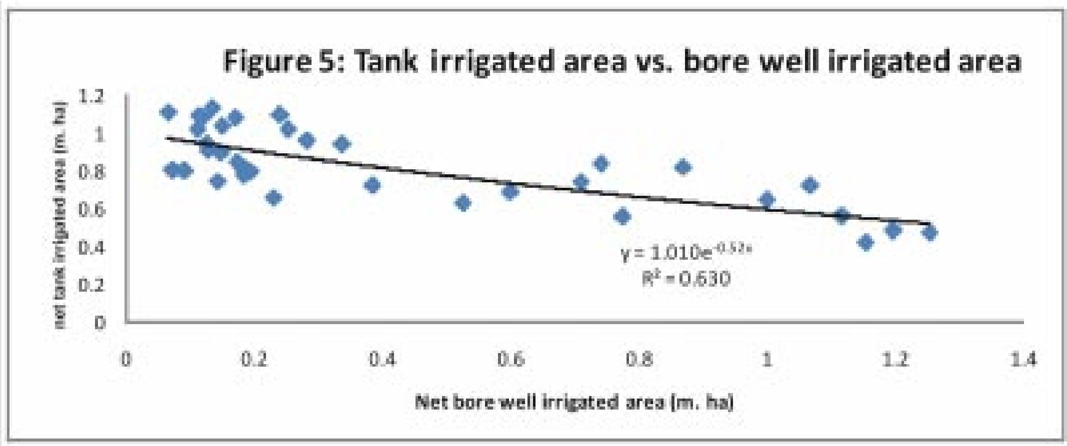
The changing share of groundwater in AP's irrigation landscape has been noted by some researchers (see Amarasinghe et al., 2007). The time series data they presented (Figure 3) on net groundwater irrigated area in the state showed a peaking in 2000 and decline thereafter. They argued that in the recent years (since 2002), the well irrigation growth has become very sensitive to rainfall. We can safely assume that groundwater irrigation has almost reached a saturation point by the year 2000-01, which basically means that the groundwater irrigation potential created by farmers in that year through wells and pump sets was sufficient to harness all the renewable groundwater resources, which occur in a good rainfall year. Making any significant gain in well irrigation in the future, except through shift in cropping pattern can be ruled out beyond doubt. Further, a colossal drain in investment took place due to farmers' rat race of competitive drilling of wells for accessing groundwater. We estimate this wastage to the tune of1648 crore rupees. This estimate was based on a realistic assumption that a farmer invests Rs.16000 for a bore well drilled in a hard rock area (based on Reddy, 2003). The total number of wells sunk during the period from 2000-01 to 2003-04 was 10.31lac by which there was hardly any additional area irrigated.

[2] The consumption went down slightly in 2005-06. This could be due to improvements in groundwater conditions, in the form of rise in water levels, which actually can reduce the energy required for lifting a unit volume of groundwater.

Negative Externalities of Well Irrigation on Tank Irrigation

Studies show tank irrigation had declined in South India. The reasons cited are: onslaught of well irrigation in the region and the consequent apathy of farmers in tanks, owing to the inherent advantage of well irrigation, deterioration of tank catchments, increased encroachment for cultivation; silting up of tanks and supply channels; and decline of traditional local institutions for tank management. But, this view point failed to look at the hydraulic interactions between aquifers and the tanks, and the physical externalities. During 1970 to 2005-06, like in other south Indian states, tank-irrigated area in AP also declined considerably. The net tank irrigated area declined from 1.11 m. ha in 1970-71 to 0.477 m. ha in 2004-05.

Strikingly the phenomenon of growth in well irrigation is causing negative externalities on tank irrigation as indicated by the strong inverse correlation that exists between net tank irrigation area and the net well irrigated area at the state level (R2=0.49). This phenomenon can be explained as follows. In many areas, particularly those located in the upper catchments of rivers, a significant portion of the tank inflows come from shallow aquifers. Increased groundwater draft from aquifers, with resultant lowering of water table can reduce the tank inflows. It can also activate percolation of tank water into the underlying aquifers, particularly with extensive de-silting of tanks undertaken by the minor irrigation department of AP government. This argument is strengthened by the inverse correlation between net bore well irrigated area and net tank irrigated area. The relationship was even stronger here (R2= 0.63) (Figure 5). Farmers generally resort to bore well irrigation in the hard rock regions, when water levels in the upper aquifer drop drastically. In other words a condition has already reached in this context where the groundwater use started influencing tank hydrology. Similar

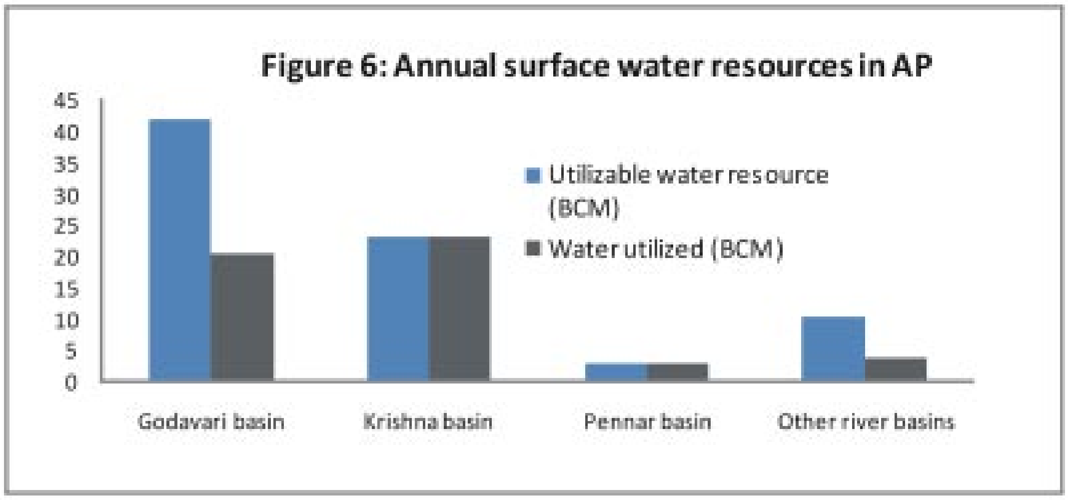


relationships were found for Chittoor (R2=0.38, and 0.53), Medak (R2=0.55, 0.66) and Anantapur (R2=0.29 and 0.44) districts, for which district-level data were analyzed.

Can Water Harvesting and Artificial Recharge Mitigate Over-exploitation?

There are many river basins in Andhra Pradesh. The most important of them are Godavari, Krishna and Pennar. Of the total geographical area, nearly 27% is in Krishna, 17.5% is in Pennar. Another 27% of the area is in Godavari basin. The rest of the area is in many of the east flowing rivers between Mahanadi to Godavari, Godavari to Krishna and Krishna to Pennar. Analysis of basin-wise runoff generation and runoff utilization shows that surface water utilization is highly skewed in the State (Figure 5). Godavari is a water-abundant river basin with annual surface runoff (dependable) of 41.9 BCM, of which only 40% of the total surface water utilized. Therefore, the basin is still “open”. So are the many small river basins between Mahanadi and Pennar. Here the degree of utilization is only 35%. As against these, the two river basins, viz., Krishna and Pennar are surface water-scarce and have already experienced high degree of water utilization with large number of reservoir and diversion schemes. The reservoir schemes include both small reservoirs like tanks and ponds and large modern reservoirs.

In AP, the problems of groundwater depletion are mostly encountered in the regions which are falling under the basins of Krishna and Pennar. This however does not mean that the entire area of AP inside these two basins is experiencing the problems. In fact, coastal areas including alluvial areas of Krishna delta, which receives water from Nagarjuna Sagar scheme, Sriram Sagar and the delta irrigation systems, are showing positive balance in groundwater, with the recharge exceeding the annual abstraction. The problems of depletion are concentrated in the areas that are not benefited by surface irrigation (Kumar et al., 2010). These areas are already facing problem of acute shortage of surface water. Though the weighted average annual rainfall



is 800mm, it varies from a highest of 1200mm in the high altitude tribal zone, to 800-1000mm in the coastal zone (Krishna, Godavari delta area) to a lowest of 500-600mm in interior

Rayalaseema region (based on Biggs et al., 2007). Hence, the regions which desperately require augmentation of groundwater are falling in “closed basins”, having no surplus runoff for recharge. Using the runoff from local catchments for recharge would mean causing negative effects for the d/s storage and diversions schemes in these basins. Already intensive water harvesting activities have caused significant negative impacts on inflows into tanks which are used for irrigation and domestic purposes in the Deccan plateau.

A counter-argument is that groundwater recharge as against storage in large surface reservoirs ensures greater returns from each drop of water used and equity in access to water from the basin. But, the aquifer underlying most of Andhra Pradesh do not have good storage space, because of the consolidated nature of the crystalline and basalt rocks. Groundwater occurs only in fractures, fissures and weathered zones. The constraints imposed by hard rock geology in recharge efforts through percolation tanks are: high depth to water table below and around the recharge structure due to occurrence of recharge mount and shallow bed rocks, which prevent percolation of water (Muralidharan, 1990 as cited in Muralidharan and Athawale, 1998); and low infiltration capacity of the thin soils overlaying the hard rock formations. Due to low specific yield (0.01-0.03), sharp rise in water levels is observed in aquifers during monsoon, leaving little space for infiltration from structures. While harnessing water for recharge is extremely important during normal and wet years, the natural recharge in hard rock formation is high during such years as it is a function of seasonal rainfall (based on regression equations shown in Figure 7 in Athawale, 2003), further reducing the scope for artificial recharge.

Soils pose additional challenges. Results obtained from short term infiltration test carried out in dug wells in Andhra Pradesh in two different soil conditions show that the infiltration rate becomes negligible (< 0.60 mm/hr) within 10 minutes of starting the test in the case of silty clay. If the infiltration rate approaches to zero fast, it will negative affect the recharge efficiency of percolation ponds. As thin soil cover has low infiltration (Muralidharan and Athawale, 1998), the extent of the problem would be larger in hard rock areas (ideal for percolation ponds) with thin soil cover. Dickenson (1994) based on several infiltration studies shows that rate of infiltration declines to a minimum value within 4-5 days of ponding. This also will have adverse effects on the performance of structures built in areas experiencing flash floods and high evaporation rates, solutions for which would be wetting or drying of pond beds through regulation of inflows. On the other hand, storage of water on the surface in small reservoirs would result in huge evaporation losses.

Would Replacing Paddy Help Reduce Groundwater Withdrawal?

Paddy is perhaps one of the most misconceived crops. The development activists and often agricultural scientists view paddy as a water guzzling crop, and an enemy of the ecology, especially when grown in semi arid or arid environment. But, there is little appreciation of the fact that the consumptive water used by this crop is only a fraction of the total water applied, particularly when it was grown under partially submerged conditions. In practice, the applied water in excess of the depleted water (also known as consumptive fraction (CF), which is the sum of ET, non-beneficial evaporation from soil strata and the non-recoverable deep percolation), would find its way to the groundwater system (Allen et al., 1998). There is no doubt that depletion of the water applied in the field could be more than the crop consumptive use, i.e., ET and this extra depletion would also be determined by the climate, soil and the depth of the dewatered zone below the crop root zone. The depletion of water can occur due to non-recoverable deep percolation and non-beneficial evaporation from the soil after harvest of the crop (Kumar et al., 2008a; Kumar, 2009; Kumar and van Dam, 2009).

But, it is not correct assume that all the water applied in the field would eventually be depleted. In areas with shallow groundwater table, permeable soils, the return flow component of the applied water could be quite significant (Watt, 2008). This is the water which actually improves the groundwater condition in canal irrigated areas in the form of recharge to groundwater. It also explains the positive groundwater balance in the deltaic regions of coastal Andhra. It is seen that a significant portion of the renewable groundwater in alluvial Punjab is from irrigation return flows from both canal and well irrigation.

Obviously, in addition to the factors mentioned above, the return flow fraction of the irrigation water applied would also be determined by the dosage of irrigation (Kumar et al., 2009), and moisture conditions in the soil profile (Watt, 2008; Kumar and Bassi, 2010). In flow irrigation, the depth of individual watering is normally high, and higher than that of well irrigation. The reason is the lesser control farmers have over irrigation water delivery in the earlier case (Kumar et al., 2009). This facilitates higher hydraulic gradient and hydraulic conductivity, increasing the velocity of downward movement of water (Watt, 2008). Since generally, groundwater table is high in canal commands the return flow gets converted into recharge to groundwater, instead of remaining in the unsaturated soil zone contributing to moisture pressure in that zone. Even in well irrigation, dosages are quite high for paddy, due to the need for putting the field under partial submergence. Further in monsoon, the moisture levels in the soil profile would be generally good, which improves with applied water, increasing both the hydraulic gradient for movement of water, and soil hydraulic conductivity (Kumar and Bassi, 2010).

In order to understand to what extent paddy contributes to groundwater over-exploitation in Andhra Pradesh, it is important to know the characteristics of the regions where the crop is grown extensively with well water, and in which season the crop is mainly irrigated. Here, we assume that the paddy field irrigated with canal water would eventually provide the return flows to groundwater, which would be available for reuse, and therefore would help augment groundwater. Similarly, paddy irrigated with groundwater during kharif season would also provide substantial return flows, with availability of rains. Experiences in paddy irrigated areas in the state show that area under upland winter paddy, which is grown with well irrigation during the second crop season, is much less in comparison to irrigated paddy in the coastal districts (source: based on Murthy and Raju, 2009). Therefore, the argument that irrigated paddy depletes groundwater in AP is open to questioning.

Can We Maneuver Energy-Groundwater Nexus for Co-Management of Electricity and Groundwater?

Of late, there has been growing recognition of the fact that subsidized and often free power supplied to agriculture is encouraging wasteful use of groundwater and electricity, apart from causing huge revenue losses to the state exchequer (see for instance, Kumar and Singh, 2001; Kumar, 2005; Murthy and Raju, 2009; Saleth, 1997). This is evident from the data provided by Murthy and Raju (2009) for three districts of Andhra Pradesh. Their comparison of energy requirement for groundwater pumping for irrigation and the actual energy consumed (Table 1) shows huge wastage of electricity used up in agricultural pumping. Part of the reason, being the zero marginal cost of electricity, while the other reason being night power supply.

Table 1: Estimated Energy Requirements and Actual Energy Consumed

	Vijayanagaram	Visakhapatnam	East Godavari
Estimated Energy Requirement	6.83	11.03	27.74
Energy Consumed	19.12	19.08	95.24
Energy Saving Potential	12.59	7.05	68.10
Percentage Energy Saving Potential	65.85	38.90	71.06

Source: Murthy and Raju (2009)

The total power subsidy for agriculture sector in Andhra Pradesh was Rs. 4,176 crore annually in 2001-02 (GOI, 2002). The amount of subsidy might have only gone up with the total electricity consumption in agriculture going up to 13,267 million units in 2005-06 from 11,055 million units in 2000-01. The power supplied to agriculture being unreliable and of poorest quality (with supply being provided during night hours with voltage fluctuations and power cuts), farmers endure frustration and huge economic cost in the form of loss of production (Monari, 2002), and thus virtually does not enjoy any subsidy. While this is true, what concerns is the marginal cost of electricity under flat rate system of pricing. It is still zero under flat rate tariff. Here, both the government and farmers loose, while both water and energy economy suffer.

[3] Since they are not able to irrigate the crop when it is most required, it has impact on the yield.

Ideally, energy supply and power pricing in farm sector can significantly influence the way groundwater is used in irrigation (Kumar, 2005; Kumar and Amarasinghe, 2009; Saleth, 1997; Zekri, 2008). The suggestions to regulate groundwater draft included improving the efficiency of pump sets (Mohan and Sreekumar, 2009), scientific rationing of power supply and metering and pro rata pricing of electricity (Shah and Verma, 2008; Shah et al., 2004). Among these three important suggestions, the second one, i.e., of scientific rationing of power supply, has attracted attention in policy circles in the state. This has been propped up by the proponents of this idea as the second best solution for co-management of both electricity and groundwater economy in south Asia, after metering and pro-rata pricing, which according to them is unlikely to work under south Asian conditions (see Shah et al., 2004 for details). This is mainly because of the much publicized "success" of Jyotigram Yojna in Gujarat, wherein separation of feeder lines for agriculture and domestic sectors, and the limited 8-hours of high quality power was supposed to have resulted in control of electricity theft, and consequent rational use of electricity by farmers for irrigated crops and therefore efficient use of water for crop production (Shah et al., 2009). Shah and Verma (2008) argued on the basis of a survey of farmers in different areas of Gujarat that this experiment has been highly successful in reducing electricity use and therefore groundwater pumping in the state. But, evidence available is a "far cry" from what their claim entails.

The fact is that the basalt and crystalline rock aquifers in the state are too poor to yield water for more than 2-3 hours in a day. Currently, power supply to agriculture is more a limited 5-6 hours a day. This is more than what farmers require to abstract the available water in their wells in most parts of Andhra Pradesh. The only exception would be coastal Andhra Pradesh in the deltaic region of basins such as Krishna and Godavari, where groundwater is abundant. This region accounts for only a small percentage of the state's geographical area. But, here again, groundwater is under-utilized and the demand for groundwater would be high only in years of drought when canal water release drops. Therefore, restriction on power supply is not going to change the way, farmers use groundwater for agriculture.

On the other hand, there is evidence from other parts of India on the role of pro rata pricing of electricity combined with reliable power supply that ensures quality irrigation can bring about on efficiency, sustainability and equity in groundwater use (see Kumar, 2005 and Kumar, 2009). Kumar (2009) showed that when confronted with positive marginal cost of using groundwater (as found in the case of well-owning farmers who pay pro rata prices for electricity, and farmers who use wells run on diesel engines), farmers use water more efficiently

---

[4] The electricity consumption in agriculture sector in Gujarat actually increased after the introduction of Jyotigram scheme from 9579 m. units to 11009 m. units, which was partly due to the fact that groundwater recharge in different parts of the state actually increased as a result of good rainfall in consecutive four years from 2002 onwards, which enabled farmers to use the available electricity to pump out more groundwater from the wells, including those which became rejuvenated, using the power connections which were lying idle. The point to be noted is that the available power supply (of 8 hours) even after rationing is much more than what is required to abstract the groundwater in most regions of the state.

in physical terms; grow crops that high higher water productivity in economic terms (Rs/m3), improve their overall farming system, and secure higher net returns from unit volume of water used at the farm level, as compared to farmers who use wells run with electric pump sets and pay for electricity on the basis of connected load. The greater control over irrigation water helps diesel engine owners apply water as and when required, thereby achieving better on-farm water management. Also, these farmers were also found to be using less amount of water per unit irrigated area, and the reduction was disproportionately higher than the reduction in net return from unit area of land (Rs/ha), making it possible to sustain the net return from irrigated farming with much less use of groundwater. Research also showed that the heavy subsidies well owning farmers enjoy under flat rate system of pricing electricity and the free electricity for groundwater pumping do not get transferred to the water buying farmers (Kumar, 2009).

Table 2: Aquifers in Andhra Pradesh

Sr. No	Type of Aquifer	Approximate Percentage Area Covered
1	Crystalline aquifer (consolidated)	50.0
2	Basalt formations (consolidated)	20.0
3	Deltaic alluvium (unconsolidated)	20.0
4	Hilly aquifers	10.0

Source: based on aquifer profile of India, CGWB

Can Drip Irrigation Save the Precious Groundwater in Andhra Pradesh?

Expectations were raised regarding the potential of drip irrigation in Andhra Pradesh, with the task force on micro irrigation set up under the Chairmanship of Chandrababu Naidu, former Chief Minister of Andhra Pradesh. For instance, Narayanamoorthy (2009) assesses that the potential of drip irrigation system in AP would be 1.68 m. ha. But, there has been no scientific assessment of the real potential for drip irrigation in the state, which involved data on the cropping systems that exist in different regions of the state, and due consideration to the conditions under which drip system becomes the best bet technology. It was argued that the drip irrigation systems would become best bet technologies when they are adopted in areas with semi arid and arid climate with deep water table conditions, for row crops, and under well or lift irrigation. Further, it was said that the water saving benefit of drip irrigation will be significant under semi arid and arid climates when used for row crops, and in areas with deep unsaturated zones. The technical feasibility and economic viability of drip irrigation would be higher for well-irrigated crops, with independent pressurizing devices; and also their economic viability better for distantly spaced crops, for which the capital cost of the system would be less. The potential area under crops that are conducive to water saving MI technologies, wherein the intended benefits could be derived, in the state was estimated to be only 5.57lac ha (Kumar et al., 2008; Kumar, 2009). Their estimate considered only the well irrigated area in AP.

Table 3: Paddy Irrigated Area (2007-08)

Particulars	Autumn	Winter	Summer	Total
Cropped Area	2577609	1406334	0	
Irrigated Area (Ha)	2443633	1406334	0	3849967

Unfortunately, none of these issues were given adequate attention while assessing the potential of drip irrigation systems in the state. As cursory look at the irrigation landscape of the state would show that nearly 3.84 million ha out of the total 6.28 m ha of the irrigated land is under paddy, i.e., 61 per cent. This area has to be excluded while thinking about drip irrigation systems. Some experiments were made with drips for upland paddy and enhanced yield recorded. They were still not found to be economically viable. The crops that are amenable to micro irrigation systems and that are grown extensively in Andhra Pradesh are groundnut, chilly, cotton, sugarcane, cotton and tobacco. They together accounted for a total area of 1008300 ha. Among these crops, groundnut is actually gives better results under micro sprinklers, and not drips. Nevertheless, it was also considered in view of the water-saving benefit it could give, when irrigated with the use of MI systems.

Table 4: Area under Crops Amenable to Micro Irrigation Systems (as on 2008-09)

Sr. No	Name of Crop	Area Irrigated (Ha)
1	Groundnut	2,94,000.00
2	Chilly	1,69,000.00
3	Sugarcane	3,18,000.00
4	Cotton	2,55,000.00
5	Tobacco	47,000.00
6	Total area under crops amenable to drips	1,083,000.00

Source: based on irrigated cropped area in AP in 2004-05, as cited in Reddy, 2007.

It is quite likely that some of these crops were also grown in canal command area because of the need for intermediate storage systems, making it difficult for adoption of MI system (Kumar et al., 2008). That would further reduce the potential of MI systems in the state. While MI systems were adopted extensively by farmers in some canal commands in Rajasthan through the use of intermediate storage systems, such storage systems are viable by virtue of large landholdings of the farmers in that region. Further, sprinklers make it possible to irrigate the otherwise difficult terrain with sloppy land and sandy soils. Hence, the actual potential of drip systems is quite likely to be close to the estimates provided by Kumar et al. (2008). Finance is going to be another major impediment for MI adoption. The actual record of MI adoption in the state is a true reflection of these structural constraints facing adoption of

[5] For instance, micro sprinklers are used in the IGNP command in Bikaner district, with the help of Diggies, which are large surface storage tanks.

drip systems. Under the much-publicized Andhra Pradesh Micro Irrigation project of the government of AP, a total area of 1.66lac ha was covered under MI systems over a time period of nearly 30 months. The total subsidy benefit to farmers was to the tune of 209.96 crore rupees, which works out to be Rs. 18,070 per ha (Kumar and van Dam, 2009). The result is that most of the farmers have installed drip systems for fruit crops, for which returns, as noted by Dhawan (2000), would anyway be high even without drips, and sprinklers which are low cost but not technically efficient for small farms (Kumar et al., 2008a). Crops such as sugarcane, chilly and groundnut would require much higher capital investment for installing drip systems as compared to the fruit crops like sweet lime. By 2008, an area of 3.28lac ha was under drip irrigation in AP as per the data provided by the Ministry of Agriculture, Government of India.

This much needed investment is least likely to come from farmers given the current mode of pricing of electricity and water followed in the farm sector, which does not create any incentive for farmers to save water (Kumar et al., 2008a; Kumar, 2009).

Community Management of Groundwater: Utopian Idea?

Much has been written about management of groundwater by local communities in India in general (Shah et al., 1998), and Andhra Pradesh in particular (Jain, 2008). Some of the initiatives such as APFMGS (Andhra Pradesh Farmer Management of Groundwater Systems) project (Shah, 2008) and APWALTA (Andhra Pradesh Water, Land and Trees Act) project have been widely acclaimed as the innovative approaches for local management of groundwater by the rural communities, never witnessed in any part of the developed world. APWALTA project was based on the premise that communities would observe self regulation under an over-arching legal framework at the state level, if supported by the village Panchayat and NGOs. Farmers' groundwater school was the cornerstone of this project. APFMGS envisaged that if farmers had the capacities to monitor groundwater resources in their localities they would have great motivation to use it judiciously.

So far as APWALTA is concerned, there are no large-scale examples of communities undertaking self regulation of groundwater, though there are some isolated cases of communities enforcing ban on drilling of deep bore wells in the villages, with the support of the Panchayats. But, unfortunately, there is no evidence of such measures addressing access equity concerns in groundwater. As regards APFMGS, it did a commendable job of training farmers in hundreds of villages and handling instruments for groundwater monitoring. These farmers could also periodically monitor wells and generate data on groundwater levels in those villages. But, such steps have not resulted in measures reducing groundwater draft such as shift in cropping pattern (from water intensive crops to low water consuming crops) or adoption of water efficient irrigation technologies.

[6] 0.19ha per capita against a national average of 0.116ha per capita (source: authors' own estimates.

Future of Water and Agriculture in Andhra Pradesh

There is very limited scientific literature available on the future of water and agriculture in AP, and the challenges posed by the growing water scarcity. In spite of the fact that the total cultivable land in the state, in per capita terms stands one of the highest among all the major states of India , and only 41% of this is irrigated currently, very little attention has been paid by international scholars working on water and food on the role of the state in addressing the future food security challenges facing the nation. With a major share of the cropped area under paddy, the contribution of the state to the central pool is remarkable. With 17.8 million ton of raw rice produced (in 2001), its contribution to the national granary is 12.8 per cent, against having only 7 per cent of country's population (Kumar et al., 2008b). Therefore, depletion of groundwater can pose a major challenge not only for the national food security, but also for the food security of millions of rural masses in the state.

We have already shown that paddy consumes only a fraction of the water which is applied, and the rest is available for re-use. A close look at the time series data on the problem of groundwater over-exploitation and area under paddy shows absolutely no correlation between the two. In fact the percentage area under paddy had reduced significantly, while groundwater abstraction has increased remarkably from 1980s through 2000.

The area under irrigated paddy went down from 81.23 per cent of the gross irrigated area in 1956-57 to 63.05 per cent in 2008-09 (Table 5). In aggregate terms, the area under irrigated paddy went up marginally from 3.83 m. ha in 1990-91 to 4.25 m. ha in 2008-09, a 10% growth over two decades, while the total irrigated area in the state increased from 5.37 m. ha in 1990-91 to 6.74 m. ha in 2008-09. Even here, the irrigated paddy area in 2007-08 was almost the same as that of 1990-91, while the state experienced a quantum jump in irrigation during these two decades (by nearly 9.15lac hectares). Now it is unlikely that the area under canal-irrigated paddy had reduced over time in the state as it is generally observed that farmers receiving canal water take up wet crops. Hence it is unlikely that area under well irrigated paddy went up over time. On the other hand, the degree of groundwater utilization went up from 28 per cent to 45% (Jain, 2008), which indicate lack of connection between paddy irrigation and groundwater depletion. Still, academic and policy debates on sustaining Andhra Pradesh's groundwater irrigation economy had to a great extent centered on reducing area under well-irrigated paddy (see Reddy and Kumari, 2007).

Table 5: Shift in Irrigated Cropping Pattern in Andhra Pradesh over Five Decades

	1956-57	1960-61	1970-71	1980-81	1990-91	2000-01	2007-08	2008-09
Rice	81.23	79.26	78.64	77.82	71.32	68.31	61.26	63.05
Cotton	0.06	0.09	0.33	0.51	1.527	3.25	3.44	3.78
Chilly	1.56	1.44	2.23	1.59	2.59	2.62	2.83	2.51
Sugarcane	2.07	2.51	2.79	3.94	4.19	5.87	6.30	4.72

Source: Andhra Pradesh Water Sector Reforms, GOAP, 2009

Table 6: Stage of Groundwater Development over Time in Andhra Pradesh

1980s	1990s	2002	2004	2007
28%	29%	43%	45%	41%

Source: Jain, 2008

But, on the other hand, the area under highly water-intensive irrigated crops such as chilly, sugarcane had dramatically increased. In the case of sugarcane, it went up from 4.2 per cent in 1990-91 to a highest of 6.3 per cent in 2007-08. The aggregate area added was 1.71lac ha. Percentage area under cotton increased from 1.52 to 3.78, and in aggregate terms the added area was 1.73lac ha. Notably, there has been phenomenal increase in area under irrigated maize in the state from 0.82lac ha to 4.21lac ha during the past two decades (from 1990-91 onwards), which accounted for 24% of the growth in irrigated area. The crop requires nearly 540mm of water, when grown during winter season in the parts of AP, where it is grown today. If we assume that all this maize is grown with well irrigation, the added pressure on groundwater resource from this crop alone would be 1804 MCM per annum. This is based on crop water requirement estimated for this crop for three districts of AP, viz., Hyderabad, Kurnool and Nellore, estimated on the basis of FAO CROPWAT for an additional area of 3.38lac ha.

There are reasons to believe that the high incidence of well failures are forcing farmers to take up crops that give very high return per unit area of land, which eventually consume large amounts of water. Since the marginal cost of groundwater abstraction is zero, they are not concerned with the return per unit volume of water. The quest to recover the huge investments being made for well drilling is likely to lead the farmers to risky crops such as chilly and cotton. This can put farmers in debt trap and sometimes resultant suicides, as found in some of the districts of Andhra Pradesh like Anantapur already. Naturally, growing of paddy would be confined to some of the water-rich regions such as Coastal Andhra Pradesh, where water from canals replenishes the groundwater resources on a more reliable basis.

In spite of being cereal surplus state and with significant exports, Andhra Pradesh continues to be one of the most food insecure states in the country. The report on the state of food security in rural India prepared by the World Food Programme of the United Nations and MS Swaminathan Research Foundation shows the average food insecurity index for AP to be in the range of 0.621-0.752 (MSSRF/WFP, 2001). This contradiction is due to the lack of purchasing power of many people in both rural and urban areas. Keeping in view the larger concerns national food security in general and the food security of poor people in the state in particular, it is important that the area under irrigated paddy is at least maintained at the current level, if not expanded. This can keep the production at satisfactory levels and keep the prices stable and affordable for the millions of poor people in the state. Paddy cultivation would also ensure absorption of large amount of rural labour force in agriculture, generating income thereby increasing the purchasing power. Given the problems of low success rates in drilling wells and high incidence of well failures and reducing well yields, well irrigators will

[7] The estimated values of crop water requirement for winter maize are 503 mm for Nellore, 552 mm for Kurnool and 546mm for Hyderabad.

have least incentive to take up paddy, which give comparatively lower returns as compared to cash crops such as chilly, groundnut, cotton, tobacco and sugarcane. Hence, what is needed is greater water security, which can come from a check on groundwater depletion.

How to Address the Growing Groundwater Crisis in Andhra Pradesh?

It is quite evident that groundwater irrigation in the state has already reached its zenith and cannot expand further unless major improvements occur in irrigation efficiencies. Efficiency improvements in groundwater irrigation in the state is a far cry given the fact that the state is indulging in more in populist measures like free power for agriculture and heavy investments in popular welfare programmes such as MREGA. Not only that these programmes have significant negative impacts on energy (in the case of free power to agriculture) (Kumar, 2005; Kumar, 2009) and labour economy (in the case of MREGA) (Bassi and Kumar, 2010), they in the long run can cause huge damages to the groundwater economy. The growing farmers' preference for growing water-intensive cash crops such as sugarcane and chilly is quite alarming.

Drip systems do not offer great potential in the present context, with large area under irrigated paddy, as the maximum area that can be brought under drips is around seven per cent of the gross cropped area, and 15 per cent of the gross irrigated area. Area under well-irrigated crops, which offer greater technical feasibility for MI adoption, would be even smaller. Efforts aimed at artificial recharge of groundwater through watershed development, small water harvesting schemes and dug well recharge schemes are not likely to bring about any improvements in groundwater balance in the areas where it is required, due to the poor surface water potential in the river basins of these areas and the poor storage potential of the hard rock aquifers. Replacement of paddy by low water consuming crops is not likely to make any significant impact on the groundwater balance, given the fact that most of the groundwater irrigated paddy is grown in kharif season during which a significant portion of the water applied to paddy field gets back into the groundwater system as return flow, contributing to groundwater balance.

Crops such as chilly, sugarcane, cotton and tobacco, and winter paddy that are irrigated by groundwater in turn deplete large amounts of groundwater. But, currently, most of the efficient micro irrigation systems are installed for orchard crops. It needs to be extended for other row crops such as sugarcane, chilly, cotton and tobacco, which are also high-valued.

Pricing of electricity appears to be the only policy instrument which government is left with to control wasteful use of groundwater. The state should embark on metering and pro rata pricing of electricity in the farm sector, keeping in view the fact that it would improve not only the energy economy, but also the groundwater economy of the state. By introducing pro rata pricing of electricity, and by improved quality and reliability of power supply, farmers would be encouraged to use water more efficiently in the field, thereby saving electricity and money. Improved quality of power would ensure that the farmers are able to irrigate the crop as and when required, protecting the crop from water stress and consequent yield losses. Also, such pricing regime is going to create strong incentives among farmers to adopt micro irrigation systems for the highly water-intensive crops, and adopt on-farm water management practices such as zero tillage, for maize. The water saved at the field level would get translated into income saving.

The very fact that farmers' investments to the tune of thousands of crore are going waste as a result of indiscriminate well drilling and high rates of well failures call for major institutional interventions to avert a major future disaster. The only way competitive well drilling by farmers can be regulated is through creation of groundwater rights, wherein the rights of individual farmers over the groundwater in aquifers underlying the land of hundreds of thousands of farmers has to be defined in volumetric terms. This has to be made tradable. This can be water use rights, rather than absolute ownership rights over groundwater. The volumetric water rights can be fixed on the basis of the renewable groundwater resource that are utilizable, using equity and sustainability considerations (Kumar, 2000; Kumar and Singh, 2001; Kumar, 2007). Under proper market conditions, volumetric water rights, if made tradable, will also ensure efficient use of water (Kumar and Singh, 2001; Kumar, 2005; Kumar, 2007). This would encourage non-well owning farmers to enter into water (physical) transfer agreements with well owners, thereby deferring the investments for new wells. It even provides opportunities for farmers to come together and decide on the number of wells to be operated at a time so as to mitigate the problems of excessive draw-downs in wells which occur as a result of large number of withdrawals happening simultaneously from a small area. Under such arrangements, the irrigation potential of energized wells could not only be enhanced, but also fully utilized.

Both the fixed and variable costs of irrigation are likely to be low under this arrangement, as fewer wells will irrigate larger area per well. Under such a scenarion, the pumping cost will be lower owing to reduced draw-downs in wells. This would encourage the farmers to stick to the irrigation service providers, rather than investing in their own wells and wasting money. The presence of large number of potential service providers might also ensure that the irrigation service (and not water) charges are highly competitive. But, establishing and enforcing groundwater rights would be an enormous task, wherein one has to deal with the science of assessing the groundwater resources in different regions with reliability, and also creating institutions for allocating and enforcement of water use rights. Kumar (2000) and Kumar (2007) had discussed an institutional framework for managing groundwater resources. It involves a three-tier hierarchy of organizations from local village institutions to watershed institution to institutions at the aquifer level. Under the framework, suggested, the institution at the higher level (aquifer management committee) is expected to assess the resource periodically; evolve norms for allocating volumetric water rights of sectors and individual users in the groundwater basin; and allocate rights to lower level institutions, which in turn will allocate rights to individual and community users . The lower level institution (village level institution) will enforce rights by monitoring the individual users. But, groundwater rights in hard rock regions will be correlative (Saleth, 1996). Further, since renewable groundwater resources are a function of rainfall, the water use rights will have to change from year to year.

[8] If markets are efficient, the price at which water is traded would reflect the opportunity cost of using water (Howe et al., 1986; Frederick, 1992). This would motivate farmers to transfer water to grow crops that are economically efficient, or use the water more efficiently for the existing crops, and sell the saved water at priced decided by the market to earn an income (Kumar and Singh, 2001; Kumar, 2005; Kumar, 2007).

[9] The institutional framework suggested is such that it can internalize some of the negative externalities in local user group management (Kumar, 2000; Kumar, 2007).

Simultaneously, the state also may look at inter-basin water transfer options more seriously. The proposed 174km long Polavaram-Vijayawada link canal which is to take off from the proposed Polavaram reservoir on Godavari River and supply water to Krishna River upstream of Vijayawada would expect to being a total cultural command area of 1.4lac ha under irrigation, in addition to releasing 2265 MCM of water into Krishna river. Godavari being a water-surplus river basin (GOI, 1999), this project offers tremendous potential for not only reducing demand-supply imbalance of water in Andhra Pradesh, but also the environmental water scarcity in the lower stretches of Krishna River. Studies by Sharma et al (2008) on the groundwater externality of this water transfer project had shown that introduction of canal water would improve groundwater regime, though may not be adequate to meet the water requirements of the region. Releasing water through the link canal during kharif for irrigation to provide supplementary irrigation to paddy would not only enhance the economic (use) value of the expensive water, but also provide the much needed recharge to groundwater in these hard rock regions. The study also showed that nearly 16% of the command area would be susceptible to water logging, which according to the study could be averted by growing paddy in kharif and winter seasons. Nevertheless, it is important to ascertain the storage potential of hard rock aquifers to absorb the seepage from canal during kharif seasons, as natural recharge from rainfall also takes place during the season.

Conclusions

The assessment of groundwater over-exploitation in Andhra Pradesh based on simplistic considerations of annual recharge from various source and abstraction provide highly misleading outcomes. Problems of groundwater depletion in the state are far more serious than what the official estimates show them to be, as evident from the growing incidence of well failures and decline in average area irrigated by a well. Indiscriminate drilling of wells, with their aggregate capacity far exceeding the utilizable resources in the shallow aquifers, is causing well interference and fast drying of shallow wells. The investments to the tune of 1,648 crore were sunk by poor farmers in the state in drilling new wells without adding an extra hectare of well irrigated area in just 3-4 years from 2000-01. It also affected tank irrigation adversely. Further, groundwater irrigation is unlikely to expand in the groundwater abundant regions, as the land in these regions is fully under irrigated production.

Given the existing cropping pattern, very little can be achieved through drip systems, which too would require large scale of public expenditure in the form of subsidies for the capital equipments. Local water harvesting and groundwater recharge interventions can achieve too little given the hydrological regime, geological setting and soil conditions of the basins viz., Krishna and Pennar which are experiencing acute water scarcity and groundwater depletion. There is no evidence of community regulation and management of groundwater in a meaningful way.

Pro rata pricing of electricity in the farm sector appears to be the only major option the state is left with to tackle the problem of inefficient energy and water use in the short and medium term. In the long-term, establishing tradable property rights in groundwater based on physical sustainability and equity consideration might be a viable option, if one considers the opportunity cost of not having it. Such institutional interventions would also put a break on wasteful expenditure on competitive well drilling. Only that can protect the investments of farmers which run into thousands of crore of rupees. This is an arduous exercise because of the inherent the scientific and institutional challenges of correctly assessing groundwater resources and instituting and enforcing water rights of individual users. But establishment and enforcement of tradable rights in groundwater in volumetric terns would ensure equity in access to groundwater and its efficient use, therefore achieving groundwater demand management (Saleth, 1996; Kumar and Singh, 2001; Kumar, 2007).

Inter-basin water transfers from water-rich basins (like Godavari basin) to water-scarce basins also holds a big promise (Sharma et al., 2008). But, the impacts of such interventions will be multiplied if we take the following measures. First: irrigation water is released for growing kharif paddy in order to ensure sufficient return flows to the groundwater as recharge. Second: part of the excess flows diverted is used for reducing the environmental scarcity of the water-stressed river, apart from using it for recreational purposes. Third: caution is exercised in ensuring conjunctive management of groundwater and surface water.

References

Allen, R. G., L. S. Willardson, and H. Frederiksen (1998) Water Use Definitions and Their Use for Assessing the Impacts of Water Conservation. Proceedings ICID Workshop on Sustainable Irrigation in Areas of Water Scarcity and Drought (J. M. de Jager, L.P. Vermes, R. Rageb (eds). Oxford, England, September 11-12, pp 72-82.

Amarasinghe, Upali, B.K. Anand, Madar Samad and A. Narayanamoorthy (2007) "Irrigation in Andhra Pradesh: Trends and Turning Points," paper presented at the workshop on Strategic Analyses of India's River Linking Project-A Case Study of the Polavaram-Vijayawada link, C Fred Bentley Conference Center, Building # 212, ICRISAT Campus, Patancheru, Hyderabad, August 30, 2007.

Bassi, Nitin and M. Dinesh Kumar (2010) NREGA and Rural Water Management in India: Improving the Welfare Effects, Occasional Paper # 3, Institute for Resource Analysis and Policy, October 2010.

Custodio, E. (2000) The Complex Concept of Over-exploited Aquifer, Secunda Edicion, Uso Intensivo de Las Agua Subterráneas, Madrid.

Dhawan, B. D. (2000) Drip Irrigation: Evaluating Returns, Economic and Political Weekly, pp 3775-3780, October 14.

Dhawan, B. D. (ed.) (1990) Big Dams: Claims, Counter Claims. New Delhi: Commonwealth Publishers.

Dickenson, J. M. and S. B. Bachman (1994) The Optimization of Spreading Groundwater Operations, in Proceedings of Second International Conference on Artificial Recharge of Groundwater, A. Ivan Johnson and R. David G. Pyne (Eds.). ASCE Publications: 630-639.

Government of India (2002) Annual Report (2001-02) of the Working of State Electricity

Boards and Electricity Departments 2001-2002, Planning Commission-Power & Energy Division, May 2002.

Jain, A. K. (2008) Challenges Facing Groundwater Sector in Andhra Pradesh, presentation by the Special Secretary to Government of AP, June 24, 2008.

Frederick, K. D. (1992) Balancing Water Demand with Supplies: The Role of Management in a World of Increasing Scarcity, Technical Paper 189, Washington D. C: World Bank.

Howe, Charles W., Dennis R. Schurmeier and W. Douglas Shaw, Jr. (1986) "Innovative Approaches to Water Allocation: The Potential for Water Markets," Water Resources Research, 22 (4), pp. 439-445, April.

Kumar, M. Dinesh (2000) Institutional Framework for Management of Groundwater Resources: A Case Study of Community Organizations in Gujarat, India, Water Policy, 2 (6): 423-432.

Kumar, M. Dinesh (2005) Impact of Electricity Prices and Volumetric Water Allocation on Energy and Groundwater Demand Management: Analysis from Western India, Energy Policy, 33 (1): 39-51.

Kumar, M. Dinesh (2007) Groundwater Management in India: Physical, Institutional and Policy Alternatives, Sage Publications, New Delhi.

Kumar, M. Dinesh (2009) Water Management in India: What Works, What Doesn't, Gyan Books, New Delhi.

Kumar, M. Dinesh and O. P. Singh (2001) "Market Instruments for Demand Management in the Face of Scarcity and Overuse of Water in Gujarat," Water Policy, 3 (5).

Kumar, M. Dinesh and O. P. Singh (2008) How Serious Are Groundwater Over-exploitation Problems in India? Fresh Investigations into an Old Issue, proceedings of the 7th Annual Partners' Meet of IWMI-Tata Water Policy Research Program "Managing Water in the Face of Growing Scarcity, Inequity and Declining Returns: Exploring Fresh Approaches," ICRISAT Campus, Patancheru, Hyderabad, 2-4 April, 2008.

Kumar, M. Dinesh, O. P. Singh and Katar Singh (2001) Groundwater Depletion and its Socioeconomic and Ecological Consequences in Sabarmati River Basin, Monograph # 2, India Natural Resources Economics and Management Foundation, Anand.

Kumar, M. Dinesh, O. P. Singh, Madar Samad, Hugh Turral and Chaitali Purohit (2008a) Water Saving and Yield Enhancing Micro Irrigation Technologies in India: When Do They Become Best Bet Technologies?, proceedings of the 7th Annual Partners' Meet of IWMI-Tata water policy research program, "Managing Water in the Face of Growing Scarcity, Inequity and Declining Returns: Exploring Fresh Approaches", International Water Management Institute, South Asia Regional Office, ICRISAT Campus, Hyderabad, 2-4 April 2008.

Kumar, M. Dinesh, M V. K. Sivamohan and A. Narayanamoorthy (2008b) Irrigation Water Management for Food Security in India: The Forgotten Realities, paper presented at the International Seminar on Food Crisis and Environmental Degradation-Lessons for India, Greenpeace, New Delhi, October 24, 2008.

Kumar, M. Dinesh and Jos van Dam (2009) Improving Water Productivity in Agriculture in India: Beyond "More Crop per Drop", in Kumar, M. Dinesh and Upali Amarasinghe (Eds) Water Productivity Improvements in Indian Agriculture: Potentials, Constraints and Prospects, Strategic Analysis of National River Linking Project of India Series 4, International Water Management Institute, Colombo.

Kumar, M. Dinesh, Kairav Trivedi and OP Singh (2009) Analyzing the Impact of Quality and Reliability of Irrigation Water on Crop Water productivity Using an Irrigation Quality Index, in Kumar, M. Dinesh and Upali Amarasinghe (Eds) Water Productivity Improvements in Indian Agriculture: Potentials, Constraints and Prospects, Strategic Analysis of National River Linking Project of India Series 4, International Water Management Institute, Colombo.

Kumar, M. Dinesh and Upali Amarasinghe (Eds) (2009) Water Productivity Improvements in Indian Agriculture: Potentials, Constraints and Prospects, Strategic Analysis of National River Linking Project of India Series 4, International Water Management Institute, Colombo.

Marechal, J.C., L. Galeazzi, B. Dewandel and S. Ahmed (2003) Importance of Irrigation Return Flow on the Groundwater Budget of a Rural Basin in India, Hydrology of the Mediterranean and Semi Arid Regions, Proceedings of an International Conference held at Montpellier, April 2003.

Mohan, RV Rama and N. Sreekumar (2009) Evolving an Integrated Approach for Improving Efficiency of Ground Water Pumping for Agriculture Using Electricity: A few Pointers from the Field, Centre for World Solidarity, Hyderabad.

Monari, Lucio (2002) Power Subsidies, Public Policy for the Private Sector, World Bank Group Private Sector and Infrastructure Network, Note Number 244, April 2002.

Muralidharan, D. and R. N. Athawale (1998) Artificial Recharge in India, base paper prepared for Rajiv Gandhi National Drinking Water Mission, Ministry of Rural Areas and Development, National Geophysical Research Institute.

Murthy, KVS Ramachandra and M. Ramalinga Raju (2009) Analysis of Electrical Energy Consumption of Agriculture Sector in Indian Context, ARPN Journal of Engineering and Applied Sciences, 4 (2): 6-9.

Reddy, M. Devender (2007) Water Management-Andhra Pradesh, Water Technology Centre, ANGRAU, Rajendranagar, Hyderabad.

Reddy, V. Ratna (2003) Cost of resource degradation externalities: A Study of Groundwater Depletion in Andhra Pradesh, Working Paper # 49, Centre for Economic and Social Studies, Hyderabad, March 2003.

Reddy, M. Devender and R. Vijaya Kumari (2007) Water Management in Andhra Pradesh, India, Indo US Workshop on Innovative E-Technologies for Distance Education and

Extension/Outreach for Efficient Water Management, March 5-9, 2007, ICRISAT, Patancheru, Hyderabad.

Saleth, R. Maria (1996) Water Institutions in India: Economics, Law and Policy. New Delhi: Commonwealth Publishers, 299p.

Saleth, R. Maria (1997) "Power Tariff Policy for Groundwater Regulation: Efficiency, Equity and Sustainability", Artha Vijnana, Vol. XXXIX. No.3. September, pp 312-322.

Shah, Mihir, Debashish Banerji, P. S.Vijayshankar and Pramathesh Ambasta (1998) India's Drylands: Tribal Societies and Development through Environmental Regeneration, Oxford University Press, New Delhi.

Shah, Tushaar, Christopher Scott, Avinash Kishore and Abhishek Sharma (2004) Energy Irrigation Nexus in South Asia: Improving Groundwater Conservation and Power Sector Viability, IWMI Research Report # 70, Colombo, Sri Lanka.

Shah, Tushaar (2008) Groundwater management and ownership: rejoinder, Economic and Political Weekly, 43 (17): 116.

Shah, Tushaar and Shilp Verma (2008) Co-management of Electricity and Groundwater: An Assessment of Gujarat's Jyotigram Scheme, Economic and Political Weekly, 43 (7): 59-66.

Sharma, Bharat, KVGK Rao and Sylvain Massuel (2008) Groundwater Externalities of Surface Irrigation Transfers under National River Linking Project: Polavaram-Vijayawada Link, Strategic Analysis of National River Linking Project, International Water Management Institute, Colombo, Sri Lanka.

Watt, Jacqueline (2008) The Effect of Irrigation on Surface-Ground Water Interactions: Quantifying Time Dependent Spatial Dynamics in Irrigation Systems, Thesis Submitted to Charles Sturt University for the Degree of Doctor of Philosophy, School of Environmental Sciences, Faculty of Sciences, Charles Sturt University, March 2008.

WFP/MSSRF (2001) Report on the State of Food Insecurity in Rural India, prepared by the World Food Programme of the United Nations and MS Swaminathan Research Foundation, New Delhi.

Zekri, Slim (2008) Using Economic Incentives and Regulations to reduce Seawater Intrusion in the Batinah Coastal area of Oman, Agricultural Water Management, 95 (3), March.

Institute for Resource Analysis and Policy is a non-profit organization undertaking research, consultancy and training in the field of natural resources management. Its goal is to promote sustainable systems for management of natural resources and their related services, particularly land and water resources, for improved food security, livelihoods and environment. The organization undertakes inter-disciplinary and multi-disciplinary research and consultancy projects. Its administrative office is located in Hyderabad, India.

Office Address:
202, Riviera, Dwarakapuri Colony, Punjagutta, Hyderabad - 500 082
Tel: 91-40-4261 7392 E-mail: info@irapindia.org www.irapindia.org

Rs: 25/-