Making ‘Rehabilitation’ Work:
Protocols for Improving Performance of Irrigation Tanks in Andhra Pradesh

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Executive Summary

In South India, tanks have been an important source of irrigation for generations. The three states of Andhra Pradesh, Karnataka and Tamil Nadu have the largest concentration of irrigation tanks, accounting for nearly 60 per cent of India's tank-irrigated area. The predominance of tanks in the Deccan plateau is because of the unique topographic characteristics of the regions.

Tanks are highly important from an ecological perspective as they help conserve soil, water and bio-diversity and also contribute to groundwater recharge, flood control and silt capture. Although most tanks were essentially constructed for irrigation purpose, they have also been used for providing water for domestic and livestock consumption. Over the years, the multiple-use dependence on tanks has only increased. Yet, in Andhra Pradesh, tank irrigated area has been declining over the years, with the net area irrigated by tanks reducing to 4.9lac hectares in 2003-04 from 7.47lac ha in 1995-96.

The rural communities were traditionally dependent on these marvelous socially engineered water harnessing systems for a variety of requirements. Hence, the impact of decline in tank systems on the rural communities is manifold. The neglect of tanks resulted in farmers receiving insufficient quantities of water from tanks. A well performing tank system has a significant bearing on the household income especially for the small farmers who have limited private resources to invest in wells and pump-sets.

Recent attempts to modernize and rejuvenate existing irrigation tanks have focused more on physical rehabilitation with little or no emphasis on understanding of the tank hydrology. Intensive crop cultivation, often in the common land through encroachments, and intensive pumping of groundwater in the upper catchments for irrigation are likely to threaten the very sustainability of the tank ecology in many areas, with serious implications for tank management programmes.

From a physical systems perspective, if performance of tanks is to be sustained or improved, it is essential to influence the land-use decisions and groundwater use in the catchment. From an institutional perspective, the domain of the conventional institutions that are being created to manage the tanks by governments and NGOs alike will have to enlarge their ambit to bring groundwater users and catchment cultivators under their fold. This calls for developing entirely new sets of protocols for tank rehabilitation, including physical strategies for tank management and institutional arrangement for ensuring their sustainable performance.

Changes happening in the rural society on the technological, socio-economic, cultural and institutional front are bringing about irreversible trends in tank ecology through changes in hydrology and water environment. Hence, schemes to improve the performance of tanks that are based on simple engineering interventions such as de-silting, catchment clearing, and supply and

distribution channel cleaning are unlikely to lead to any beneficial outcomes. In other words, if the rehabilitation programme has to be successful, there should be sufficient incentive among the potential tank users to take up the rehabilitation work. The incentives would be determined by the extent to which the improvement in tank ecology would contribute to the livelihoods of the potential users that the tank is likely to serve. This would be heavily influenced by a range of physical, socio-economic factors that characterize the tanks.

Objectives and Approach

The goal of this research project is to develop protocols for tank rehabilitation in Andhra Pradesh, comprising development of criteria for selection of tanks for rehabilitation, and the management strategies to be followed in rehabilitation of tanks for improved performance. The specific objectives were as follows: a] analyze the impact of well development and groundwater intensive use in the tank catchment and commands on tank performance in terms of irrigated area; b] analyze the impact of catchment cultivation practices on tank performance in terms of area irrigated; c] identify the physical, socio-economic, institutional and environmental factors that result in good overall performance of tanks; and, d] evolve the criteria for selection of tanks for rehabilitation, and work out the broad management strategies for sustaining and improving the performance of the selected tanks.

The study involved an eclectic approach. It used analyses of primary data collected from selected well-performing and non-performing tanks, which were both quantitative and qualitative in nature for six selected systems along with secondary data collected from the state minor irrigation department on tank and well irrigation and land use in catchments (on a time scale) at different scales (state, district and individual tanks) for addressing the key research questions. The tanks were selected in such a way that the hydrological and socio-economic environments are not uniform. The districts from which tanks were chosen for the primary survey are: Kurnool, Nizamabad and Vizianagaram. Two tanks, one well performing and one not-so well performing, were selected from each district.

Findings

- An extensive review of the past research initiatives on tanks reveal a heavy bias in the focus on sociological aspects. The factors to which the studies have attributed the “decline” of tanks are largely social and institutional.

- The arguments relating to collapse of traditional institutions as the cause of “tank decline” are based on a firm view that the external factors, which have potential influence on the tank performance, were within the control of these institutions. But, there are several physical and socio-economic changes, which could have impacted on tank performance, and are not within the control of these institutions. The past studies inadvertently ignored the fact that these institutions existed in a certain socio-political framework, which cannot be recreated. Again, such views are based on the assumption that simply carrying out the engineering interventions would yield results in terms of improved storage in tanks and expanded irrigation benefits.

- These factors at best became contextual variables for tank deterioration, and not explanatory variable as the causality has not been tested. Conversely, it is probably the decline in tank performance due to extraneous reasons which had resulted in community's disinterest in their management, with the cost of maintaining them surpassing the actual benefits that can be accrued from their upkeep.

- The alternative hypothesis proposed in this study is that excessive groundwater draft characterized by groundwater irrigation in the tank catchment and commands, and land-use changes in the catchment in the form of intensive crop cultivation resulted in reduced tank inflows, causing decline in area irrigated by tanks.

Following are the findings emerging from the empirical study.

- Groundwater irrigation has been growing steadily in Andhra Pradesh since the early 70's till the end of the last century. This has been evident through increase in number of deep bore wells and energized pump sets for open wells and bore wells. The net well irrigated area began to "plateau" after 2000-01. Thereafter, the increase in number of wells had not resulted in increase in gross well irrigated area either.

- Analysis of the dynamics of interaction between groundwater and tanks at the level of the state and districts showed that increased groundwater draft adversely affected the performance of tanks. Therefore, much of the expansion in well irrigated area happened at the cost of tank irrigation. Nevertheless, the effect of well irrigation on tank performance has not been uniform. While in many districts, the decline in tank performance in terms of "net area irrigated by tanks" in response to increase in "net well irrigated area" has been clear, in some districts, there has not been much reduction in the net tank irrigated area, in spite of remarkable increase in well irrigated area.

- Hence, though the net increase in well irrigated area in the state has been a remarkable, with 1.4 m. ha, (net), the overall contribution of wells to expansion of irrigation in the state would be much less, if one takes into account the fact that the reduction in net tank irrigated area is around 0.60 m. ha. But, the reduction in tank irrigated area cannot be fully attributed to groundwater over-extraction, and part of the reduction might have been caused by the change in land use in the tank catchments.

- There is an inverse (logarithmic) relationship between the "irrigation-wetland area ratio" and the reduction in tank-irrigated area, defined in percentage terms. Greater the value of the wetland-irrigation ratio, lower the reduction in area irrigated over time. Further, tanks with wetland-irrigation ratio in the range of 2.0-5.0 experienced an average reduction in irrigated area of 73.5 per cent. Therefore, the tanks with low irrigation-wetland ratio are likely to deteriorate much faster than those with high irrigation-wetland ratio.

- Different types of changes occurring over time in the tank catchments have significant impact on runoff affecting the hydrology and performance of tanks. The first type of change is in the area under cultivation in the catchment. The catchments of tanks are generally public land with government forests, pasture land and revenue wasteland. Barring the reserve forests, these catchments are increasingly being encroached-upon by individual villagers for cultivation.

- Access to well irrigation is a factor which triggers intensive land use in the catchment. With water available from wells, farmers are able to take up cultivation of kharif crops even in the predominantly dry regions of the country. Intensive groundwater irrigation in the catchment had double impact on tank hydrology, first by affecting the groundwater outflows into streams and the second by affecting the runoff from the catchment.

- Cultivation alters the catchment hydrology by reducing the runoff generation potential of the incident rainfall and by impounding part of the generated runoff in the cultivated fields. Often, afforestation activities are undertaken in the catchment by community organizations, which affect runoff generation. Such changes are occurring everywhere in the rural landscape. Thus, in areas which have experienced significant changes in land use in the form of extensive catchment cultivation, it won't be economically prudent to invest in tank rehabilitation.

- The use of clayey soils in the catchment and tank bed for brick making cause another type of land use change. With booming construction activity in the state, there is mounting demand for bricks. Such activities can also change the runoff or storage potential of the tank catchment, depending on the place from where the soil is excavated. In such situations, the communities or the local Panchayats will not have much interest in reviving the tanks as the income earned from such activities is very high.

- The third type of change is the interception of the drainage lines in the catchment, due to construction of roads and buildings and indiscriminate construction of water harvesting structures such as check dams in the name of watershed development. The absence of any kind of regulations on water resources in the state had actually precipitated into a serious concern. Here again, such actions are noticeable in areas with poor groundwater potential, and not in groundwater rich alluvial areas. In such areas, it won't be economically prudent to invest in large-scale tank rehabilitation.

- The degradation of tanks occurring as a result of changes in tank hydrology also seems to affect the success of the rehabilitation programme. It was observed that in the case of Kurnool and Nizamabad districts, more money was spent for rehabilitation works of those tanks which are actually not performing well as compared to the good ones. In spite of this, the condition of poorly-performing tanks did not improve.

- To sum up, groundwater intensive use in upper catchment or lower catchment will have the most remarkable impact on hydrology and performance of tanks. .

Protocol for Tank Rehabilitation

- Prior to the selection of any tank for rehabilitation, the potential of its catchment to yield sufficient water as inflows into the reservoir needs to be ascertained. For this the catchment yield with 75% dependability could be considered. The estimate of catchment yield should be compared against the total water demand for competitive uses that exist for the tank under consideration like irrigation, domestic and livestock use and fisheries. Only those which offer sufficient physical feasibility should be taken up for rehabilitation. Tanks which receive inflows to the full storage capacity or sufficient water to meet the demand of the design command area in three out of four years, should receive highest priority for rehabilitation. But this vital hydrological data on stream flows, which is an important input for hydrological planning of tanks, are not available for most tanks that either falls under the jurisdiction of Minor Irrigation department or the village Panchayats.

- It is imperative to study the land use in the tank catchment and command thoroughly, before embarking on rehabilitation of the tank system. It is quite evident that for catchments which have undergone major changes in land use, new models for runoff estimation will have to be developed. The use of "rational formula" for runoff estimation can lead to under-estimation or over-estimation of dependable runoff. The most pragmatic approach for estimating dependable yield from tank catchment would be to estimate runoff for historical rainfall for the current land use in the catchment using US Soil Conservation Bureau's Curve Number method, and then estimate the runoff of certain dependability.

- For arriving at the net stream flows, the groundwater outflows into tank inflows or tank infiltration into underlying aquifers can be computed by incorporating the groundwater draft from catchments and command in water balance models. In many situations, it may be necessary to redesign the tank command on account of the changing land use in the catchment and tank hydrology, and the new cropping systems in the area.

- For estimation of water demand for irrigation, kharif paddy in the entire command, and a short duration winter crop in $1/4^{th}$ of the command can be considered. For this, the existing cropping pattern of the area and the most desirable cropping pattern from the point of view of agro climate should be used as the basis. In the case of paddy, the amount of irrigation required during a normal year could be considered for demand estimation.

- In the case of cascade tanks, the upper catchment tanks should receive highest priority, if they require repair or rehabilitation. This is because they are least likely to face problems of encroachment, change in land use in the catchment and intensive groundwater development in the catchments and command areas, by being located in forest catchments.

Quantitative Criteria for Choosing Tanks for Rehabilitation

1. Choosing any tank for rehabilitation would involve certain costs: The costs are for micro level hydrological studies to estimate the water availability from the catchment and the demand for water in the tank command. Therefore, it is necessary to evolve simple and quantitative criteria for short-listing tanks for conducting detailed investigation, to finally decide on the nature of rehabilitation.

2. The tanks which have relatively higher "irrigation-wetland area ratio should be given priority as they are likely to experience lesser deterioration. One of the hydrological explanations for this is that such tanks would have higher losses from percolation as a result of increased groundwater draft. In areas where fishery is a major economic activity preferred by the tank communities, then the minimum water required in the tank for fish production should be considered instead of water requirement for winter crop production, for assessing the suitability for rehabilitation work.

3. Tanks with low density of wells in the command area and catchment area and low intensity of land use in the catchment need to be given priority while selecting tanks for rehabilitation. A well density of twenty and above for 20 ha of command area is a clear sign of diminishing importance of tanks for the farmers' livelihoods. On the other hand, a well density of 0.5 and above is a clear indication of high intensity of land use in the catchment area, with multiple cropping.

4. Large number of wells in the tank command may also indicate reducing importance of tanks in the livelihoods of farmers, though inverse may not be true. The argument that farmers abandon tanks because of wells is not true. On the contrary, owing to deteriorating condition of tanks, farmers are forced to go for well drilling in the command, wherever geo-hydrology permits. The effect of well density and catchment land use intensity on tank inflows would also depend on the rainfall of the region and the physiographic features of the catchment. In high rainfall regions with steep slopes in the catchment, the norm could be relatively flexible, whereas in semi arid and arid regions with low to medium rainfall, the norm will have to be more stringent.

Conclusions

To conclude, the protocol for tank rehabilitation should include estimation of the actual yield potential of the tank catchment. This would require thorough understanding of the catchment land-use, to be incorporated in the runoff estimation models which use historical rainfall data for several years to estimate the dependable yield. Groundwater draft from the catchment and command can then be simulated in a water balance model to compute the groundwater outflows into tanks or tank infiltration into aquifer for arriving at net catchment. This should be followed by realistic estimation of the water demand in the command. In the case of cascade tanks, the upper catchment tanks should receive highest priority in rehabilitation programmes.

Finally, some simple and quantitative criteria were identified to shortlist tanks for detailed studies which would help in investment decision making on rehabilitation. To begin with, tanks which have relatively higher "irrigation-wetland area ratio" (above 5.0) should be given priority for rehabilitation. The other useful criteria are density of wells in the catchments and command, and land use intensity in the catchment. Higher the values of these variables lower the feasibility of doing successful rehabilitation to improve tank performance.

INTRODUCTION

Tanks have been an important source of irrigation in India for generations. The states of Andhra Pradesh, Karnataka and Tamil Nadu have the largest concentration of irrigation tanks, numbering 1.2lac (Palanisami *et al.,* 2010), and accounting for nearly 60 per cent of India's tank-irrigated area (Karthikeyan, 2010). They play the vital role of harvesting surface runoff during monsoon and then allowing it to be used later. The predominance of tanks in the Deccan plateau is because of the unique topographic characteristics of the regions. The areas falling under these regions offer ideal potential for tank construction and carrying out gravity based irrigation (ADB 2006).

Tanks are very important from an ecological perspective as they help conserve soil, water and bio-diversity (Balasubramanian and Selvaraj 2003). In addition, tanks also contributes to groundwater recharge, flood control and silt capture (Mosse, 1999). Although most of the tanks were essentially constructed for irrigation purpose, they have also been used for providing water for domestic and livestock consumption. Over the years, the multiple-use dependence on tanks has only increased. The tank irrigated area has been declining in India over the years. In Andhra Pradesh, figures are more alarming with the net area irrigated by tanks reducing to 4.9lac hectares in 2003-04 from 7.47lac ha in 1995-96, a decline of 35% (*Source:* Ministry of Agriculture, Govt. of India).

The impact of decline in tank systems on the rural communities, who have been traditionally dependent on these marvelous socially engineered water harnessing systems, is manifold. This dependence is not only for water for irrigation and domestic use but also for the forestry, fisheries, brick-making, manure and fodder. The neglect of tanks has resulted in farmers receiving insufficient quantities of water from tanks (Palanisami 2006). A study conducted in tank irrigated areas of Tamil Nadu estimated reduction in crop yield and income for tank dependent farmers owing to growth of private well irrigation and deterioration in tank performance (Kajisa *et al.* 2004). Thus a well functioning tank system has a significant bearing on the household income especially for the small farmers who have limited private resources to invest in wells and pump-sets.

Recent attempts to modernize and rejuvenate existing irrigation tanks have focused more on physical rehabilitation with little or no emphasis on understanding of the tank hydrology. Particularly, the way land-use changes in the catchment are affecting tank inflows and siltation rates etc. have been paid least attention by those who are involved in tank rehabilitation programmes. The fact is that intensive crop cultivation, often in the common land through encroachments, and intensive pumping of groundwater in the upper catchments for irrigation are likely to threaten the very sustainability of the tank ecology in many areas. Intensive cultivation will impound a significant share of the catchment runoff; whereas excessive groundwater pumping in hilly areas can reduce groundwater outflows into stream, which constitute part of the tank inflows downstream.

If it is so, this will have serious implications for tank management programmes. From a physical systems perspective, if performance of tanks is to be sustained or improved, it will be important to influence the land-use decisions and groundwater use in the catchment. From an institutional perspective, the domain of the conventional institutions that are being created to manage the tanks by governments and NGOs alike will have to expand to bring groundwater users and catchment cultivators under its fold. This calls for developing entirely new sets of protocols for tank rehabilitation, including physical strategies for tank management and institutional arrangement for ensuring their sustainable performance.

DECLINE OF TANKS: CONTESTED TERRAINS?

Tank irrigation technology in South India is several centuries old, and in the view of some scholars (see Shah, 2008; Sengupta, 1985; Shankari, 1991) are commendable examples of the cultural and environmental superiority of traditional knowledge that existed. South India tanks are no less than legends. This is evident from the fact that during the past three decades, numerous scholarly works were carried out on these systems, mostly looking at the importance of these water harnessing systems in the socio-cultural life, and contribution of tanks in agricultural prosperity and rural livelihoods in the region. As Sharma (2003) pointed out, "there is a large volume of literature on tanks, mostly focusing on the dynamics of tanks in Tamil Nadu", which is historically known for tank irrigation. Andhra Pradesh and Karnataka are other states where as much as 40% and 44%, respectively of the net irrigated area were from tanks, even in the late 50s and early 60s (Paranjape *et al*., 2008).

A large volume of literature is exists on "decline" of tanks in South India. This "decline" is both in terms of declining relative contribution of tanks in irrigated area, and reduction in aggregate area under tank irrigation (Sharma, 2003). However, the theory of "decline of tanks" is contested by a few scholars, who believe that this emerges from a very reductionist approach of viewing tanks as mere sources of irrigation, and that the criteria for evaluating the performance of tanks should be more broad, to accommodate their various social, economic and ecological functions (Kumar, 2002; Palanisami *et al*., 2010). Kumar (2002) for instance, argue that given the wide range of physical, social, economic and ecological functions which tanks perform, the simplistic criteria for evaluating the performance of tanks, which look at the irrigated area or the number of users of drinking water as the indicators, need to change and more complex criteria need to be evolved.

Nevertheless, various theories have been made as reason for the "decline of tanks" in South India. Shankari (1991) points out that poor management is primarily responsible for the decline of tanks, as evident in the nonparticipation of farmers in cleaning channels, encroachment of the tank bed, inadequate repairs, weed infestation and siltation (Shankari, 1991). Von Oppen and Subba Rao (1980), based on a survey of 32 tanks in Andhra Pradesh and Maharashtra, argued that increases in population density resulted in deforestation in catchment areas leading to soil erosion and siltation. After, Sekar and Palanisami (2000), tank bed cultivation and the lack of an administrative structure to provide timely repair and maintenance, contributed to the decline of tank irrigation. The other reasons provided by scholars include: agricultural encroachment of supply channels and tank beds, which reduced the inflows into the tanks (Easter and Palanisami 1986, Mosse 1999); sand mining of supply channels; rural infrastructure development interfering with the natural inflows; and unplanned watershed development cutting off the supply to tanks (ADB 2006, Palanisami 2006); decline in tank storage capacity over the years due to excessive siltation (Gunnell and Krishnamurthy 2003, Paranjape *et al.* 2008); lackadaisical attitude of micro-level institutions managing the tanks, which has mainly stemmed from the growth of private well irrigation in the tank command area resulting in disincentive among farmers to manage these open access bodies (Balasubramanian and Selvaraj 2003, Kajisa *et al.* 2004, Sakthivadivel *et al.* 2004, ADB 2006). A few scholars have also highlighted how the hydraulic interdependence between tank storage and aquifer recharge is creating disincentive for farmers to carry out maintenance of tanks, and instead motivating them to privatize these resources by using them as percolation ponds (Sakurai and Palanisami 2001).

A multi-variate analysis by Balasubramaniyam and Bromley (2002) of the factors responsible for tank degradation showed that variables such as encroachments in catchment and water spread area and the increase in canal- and well-irrigation, had significantly increased the degradation of tanks. The increasing importance given to modern irrigation systems, larger reservoirs and river valley projects and the spread of private irrigation wells, also have a considerable negative impact on traditional community irrigation systems.

A common view which emerges from the review is that the lack of interest of command area farmers in the management of tanks (Shankari, 1991; Balasubramaniyam and Bromley, 2002; Sekar and Palanisami, 2000; Von Oppen and Subba Rao, 1980), or the erosion of the community management structures, which were responsible for their management, and the subsequent management take over by the government, had resulted in their decline (PRADAN, 1996; Rao, 1997). Some attributed the loss of community interest in tanks to the advent of groundwater irrigation which gave farmers superior control over irrigation (Dhawan, 1985; Palanisami, 1991). Some scholars attribute it to the development approach followed during the British rule centered on modern large irrigation systems for the decline of tanks (Paranjape *et al*., 2008).

However, Mosse (1997; 1999) challenged the long held view of scholars working on tanks in South India that collapse of community institutions was the major cause of decline of tanks. He contends that even in the past, communities did little investment in the upkeep of tanks. It was the Zamindars and kings who, not only built most of the tanks, but spent money for their upkeep as well. According to Mosse (ibid), it was the fall of the institution of overlords that led to the decline of the tanks.

Esha Shah (2008), while highlighting the cultural and environmental superiority of traditional knowledge that built and managed tanks, as an irrigation technology, argued that tanks have not necessarily produced a democratic social order, either in the past or in the present. According to her, they symbolized an increasingly extractive statecraft involving coerced labor; the expropriation of surplus by elites; and the spread of technological choices that could be environmentally unsound and that often resulted in forced displacement, uncertainty, technological vulnerability, and social anxiety and violence. Further, tanks as techno-sociological artifacts were socially embedded in societies and economies that were organized for warfare, and that sustained sharp social hierarchies, and were often violent to women and people from lower castes (Shah, 2008: p 673).

In nutshell, when viewed together, the work by various scholars seem to suggest that decline of tanks was due to several events, starting with the takeover of community and Zamindari (Private) tanks by the state, which led to institutional erosion, collapse of the system for collection of water charges and lack of maintenance leading to deterioration of the physical condition of this irrigation infrastructure, and the subsequent gradual loss of community interest in their affairs. Therefore, the factors responsible for decline of tanks were argued to be “institutional”.

None of the above theories could fully explain the reasons for degradation of tank systems and decline in tank irrigated area in South India. In fact, every argument suffers from weaknesses. For instance, if the argument that advent of groundwater irrigation had really led to the loss of farmer interest in tanks, is valid, then it tends to assume that groundwater irrigation is highly equitable and provides farmers from all segments access to and control over well irrigation. This is far from the truth, as pointed out by Kumar (2007). Only a small fraction of the small and marginal farmers in India even today own wells, and pump sets (Kumar, 2007), where the situation was much worse in the 70s and 80s, when drilling wells was expensive, and rural electrification was poor.

As pointed out by Narayanamoorthy (2007), it is the small and marginal farmers, who do not own irrigation wells in the tank commands, who have high stakes in tank irrigation as their livelihood is heavily dependent on it. If this is the case, one cannot explain the poor state of affairs with regard to the condition of tanks in areas such as Kolar (in Karnataka) and Anantapur in AP, where the poor small and marginal farmers do not own wells, and are often dependent on water purchase from well owners engaged in water trading. It is also a notable fact that most of the beneficiaries of tank water for irrigation are small and marginal farmers.

The dominant theories, advanced by many researchers, harp on collapse of traditional tank institutions as the cause of decline of tank irrigation, be it the institutions of overloads, or community management structures. Both the theories are also suggestive of a resounding view that management of tank as a system is very much within the control of the farmers in the command areas or the institutions which manage them. They inadvertently ignore the fact that these institutions existed in a certain socio-political landscape, which is difficult or even impossible to recreate. Such views are based on the assumption that simply cleaning supply channels, or clearing the catchments or repair of the tank embankments (tank bunds), and de-silting of the distribution network would yield results in terms of improved storage in tanks and expanded irrigation benefits. This again is not based on the realities concerning the performance of tanks.

NEED FOR POSTULATING AN ALTERNATIVE HYPOTHESIS ON TANK DEGRADATION

The dominant views about the decline of tanks seem to ignore the effect of endogenous and exogenous physical and socio-economic factors on tank hydrology, and the very impact these effects have on the viability of institutions itself. We would explain them in the subsequent paragraphs.

First: population growth had a significant demand on irrigation water for crop production in these semi arid regions, which forced farmers to go for alternative sources of irrigation, and the search for this alternative was facilitated by advent of well irrigation, cheap drilling technology, rural electrification and subsidized electricity for pumping groundwater. This is quite understandable given the fact the performance of tanks was subject to high variability in accordance with year to year variation in the occurrence of monsoon rains, as these tanks harnessed water only from the local catchments. Further, with a manifold increase in rural population and with increase in number of farmers within the limited command of these tanks, the actual area which a single farmer could irrigate using tank water became too low for them to manage their farming enterprise. Well irrigation not only became affordable and in some cases cheaper, it also provided a superior form of irrigation. Yet, as noted by Narayanamoorthy (2007) and Paranjape *et al*. (2008), for the poor small and marginal farmers, the tanks continued to be an important source of irrigation and livelihoods.

Second: the increase in population pressure on private land also meant that farmers had to expand the net area under cultivation, and sometimes this led to encroachment of commons, which formed the original catchments of tanks. Catchment cultivation resulted in a lot of the runoff generated from precipitation being captured through *in situ* water harvesting for production of rain-fed crops, reducing the inflows into the tanks. Intensive well irrigation on the other hand led to reduced groundwater outflows (base flow) into the upper catchment tanks. Whereas draw down in water table resulting from excessive withdrawal of groundwater can potentially lead to greater percolation of water from tanks into the shallow aquifers, further reducing the storage and irrigation potential of the tanks. It is important to mention here that as research has shown in the past, in hard rock areas of peninsular India, the “cone of impression” produced at the bottom of tanks due to percolation of tank water into the shallow aquifer generally stops further percolation of the water (Muralidharan and Athavale, 1998). This peculiar geo-logical and geo-hydrological setting ensured storage of water in the tanks in peninsular India. But, emptying of the aquifer could induce sustained recharge. What is important is that there is no mechanism to control groundwater abstraction by well irrigators in the command and catchments, as legal rights to groundwater are attached to landownership rights.

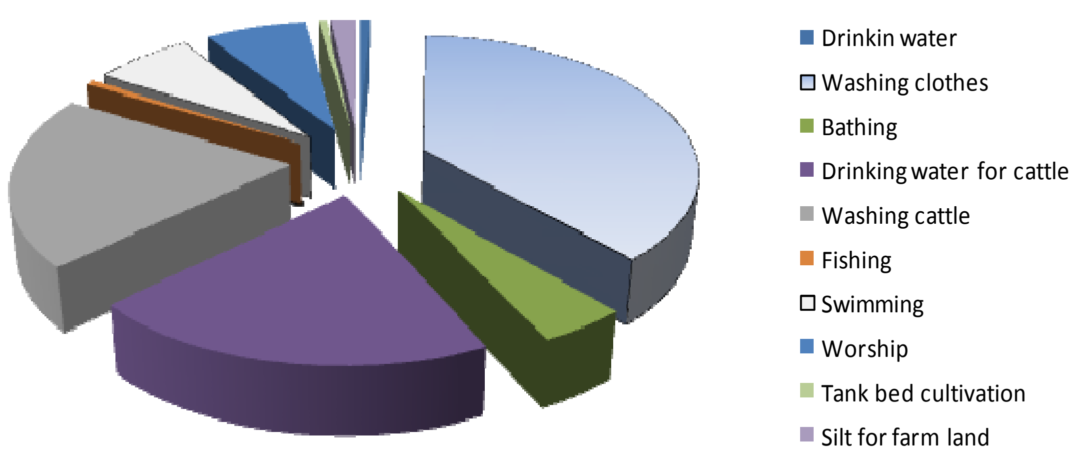
Reduced irrigation potential of tanks due to the above cited reasons and the increasing number of tank water users in the command area essentially meant that the contribution tanks could make in the overall livelihood of individual command area farmers, including small and marginal farmers, was too small in comparison to the transaction cost of initiating actions that would improve their performance. In fact, the transaction cost of initiating actions such as removal of encroachments from catchments, and regulating the use of groundwater in the command and catchment would be too high owing to the complicated legal formalities involved, whereas what a farmer could earn in terms of income from crop outputs that can be produced from the use of tank water could be quite insignificant. Whereas, many of the other engineering interventions such as stabilization of tank bund, increasing the capacity of tank through de-silting and clearing of tank catchments do not result in incremental benefits that commensurate with the financial investment in most situations. This significantly reduced the incentive among the members of the farming community for self-initiated management actions.

While there are a few tank management activities which can provide substantial private benefits (to the farmers) such as de-silting, i.e., removal of silt and clay from the tank bed, as the use of it in the field gives direct income benefit to them in terms of higher crop yields for two to three years consecutively (Kumar *et al*., 2011; Paranjape *et al*., 2008), often the communities lack the wherewithal to take it up. This also explains why the communities come forward to take up tank management activities in situations where there is external support to cover the transaction cost, and the cost of undertaking physical activities, enabled through government and donor funding.

While the tank potential for meeting the demands for economic activities has been gradually declining in many areas due to the problems described above, improved availability of good quality water from public water supply schemes within the close vicinity of their dwellings has, to a great extent, reduced the dependence of village communities on traditional sources of water such as tanks and ponds for domestic water supplies. Instead, they now they now depend on these tanks for livestock drinking and washing. Figure 1, based on data collected from four tanks in the upper catchment of Tungabhadra shows that only 1.4 per cent of the total families served by the tanks actually use it for (direct) drinking purpose. Nearly 76 per cent of the families use it for cattle drinking and cattle washing (source: based on Paranjape *et al*., 2008).

This has reduced the village communities' incentive and motivation to protect tank water quality for ensuring potability. Simultaneously, the tanks and ponds have become the natural sink for agricultural runoff containing fertilizer and pesticide residues from upper catchments. This is particularly the case for cascade tanks, wherein the upper catchments of some tanks consist of the command area of the tanks located upstream. Presence of nitrates in agricultural runoff had caused eutraphication of tanks and ponds, more so in the case of high rainfall areas, affecting fish

Figure 1: Percentage HHs using tank for various purposes



populations in these wetlands.

While it is extremely difficult to say which process has resulted in what outcome, the growing awareness of public health impacts of poor water quality, and recognition that traditional water bodies have increasingly become polluted had also forced the government to think about formal water supply for villages. Here again, it is not just that the communities have lost interest in protection of tank water quality. There could be situations where there are no alternative sources of water supply in the village. In such cases, even if the communities desire to protect the tanks from pollution, there is hardly anything which it can do to stop it as pollution is the result of agricultural intensification with more irrigated crops and intensive dairy farming. Here, both the polluters and those who suffer the damage caused by pollution are in most cases the same. But, there is a lack of institutional capability to address this issue.

All these factors might have ultimately led to tank degradation in terms of water availability and water quality wherever it has happened. Or in other words, attributing the decline of tanks to one causal factor, i.e., erosion of community institutions or collapse of traditional village institution of "Zamindari" system would be mere over-simplification of a complex physical, socio-economic, cultural, environmental and institutional change. Again, what has really led to decline of tanks in a particular situation is very much case-specific, depending on how the physical, socio-economic, cultural, environmental, and institutions factors have played out in that particular case. But, in sum, we would like make the proposition that technological, socio-economic, institutional and cultural changes happening in the societies within which the tanks are embedded, have resulted in major physical (hydrological and environmental) changes in the tank ecology, which had changed the incentive structures for tank management.

The schemes of minor irrigation departments, NGOs and donor communities in rehabilitation of tanks have their accent on engineering works viz., bund stabilization, construction of weir and repair of sluices, catchment forest clearance and channel de-silting, and institutional development, comprising formation of water user associations and their training for capacity building. They do not pay much attention to the hydrological characteristics of tanks, which are chosen for rehabilitation. Hence they produce poor results, in terms of improving the overall tank performance.

WILL THE MODERN REHABILITATION APPROACH WORK IN THE CURRENT FORMAT?

If changes happening in the rural society on the technological, socio-economic, cultural and institutional front are bringing about irreversible trends in tank ecology through changes in hydrology and water environment, then programmes and projects to improve the condition and performance of tanks that are based on simple engineering interventions such as de-silting, catchment clearing (removal of trees), and supply and distribution channel cleaning (silt removal) are unlikely to lead to any beneficial outcomes. Or in other words, if the rehabilitation programme has to be successful, there should be sufficient incentive among the potential tank users to take up the rehabilitation work. The incentives would be determined by the extent to which the improvement in tank ecology would contribute to the livelihoods of the potential users that the tank is likely to serve. This would be heavily influenced by a range of physical, socio-economic factors that characterize the tanks.

RESEARCH GOAL AND OBJECTIVES

The goal of the research project is to develop protocols for tank rehabilitation in Andhra Pradesh, comprising development of criteria for selection of tanks for rehabilitation, and the management strategies to be followed in rehabilitation of tanks for improved performance. The specific objectives were as follows:

i. Analyze the impact of well development and groundwater intensive use in the tank catchment and commands on tank performance in terms of irrigated area;

ii. Analyze the impact of catchment cultivation practices on tank performance in terms of area irrigated;

iii. Identify the physical, socio-economic, institutional and environmental factors that result in good overall performance of tanks; and,

iv. Evolve the criteria for selection of tanks for rehabilitation, and work out the broad management strategies for sustaining and improving the performance of the selected tanks

Here, the overall tank performance is evaluated in terms of the gross tank product.

APPROACH AND METHODOLOGY

The study involved an eclectic approach. It used analyses of primary data collected from selected performing & non-performing tanks, which were both quantitative and qualitative in nature (for six selected systems) along with secondary data collected from the state minor irrigation department on tank and well irrigation and land use in catchments (on a time scale) at different scales (state, district, block and individual tanks) for addressing the key research questions. The tanks were selected in such a way that the hydrological and socio-economic environments are not uniform. The specific methodology to be adopted for addressing the key research questions are described below, against each objective. The specific methodologies designed to realize each of the research objective are discussed below.

Objective I and II:

Macro level time series data on area irrigated by tanks and the area irrigated by wells were collected and analyzed using regression models to analyze the effects of groundwater irrigation. The first set of variable was used as independent variables and the second set of variables as dependent variable. The time frame was 35-40 years. The unit of analysis was districts as well as the state, in order to avoid problems of attribution. Here again, the districts, which have the highest area under tank irrigation (aggregate terms) were picked up for the district level and block level analysis, respectively.

This was supported by the analysis of quantitative data and qualitative insights obtained from the village tank user communities to understand the way the exogenous factors such as catchment land use influenced the performance of tanks in their area over the years, through participatory research methods.

Objective III:

A detailed study of six tanks, including three which are highly performing and three others which are poorly performing, was carried out and their performance compared. The performance attributes was decided in the course of the study. Some of the indicators for performance were: a] average area irrigated by the tank against the command area over time (irrigated area ratio); b] the physical condition of the tank (condition of the bund, reservoir area, waste weir & sluices and water distribution channels); c] the economic activities revolving around the tank (in addition to irrigation) and the surplus value generated from the same annually (fisheries, agro forestry, silt-use, tank bed cultivation); and, d] equity in distribution of water from the tank.

Along with these, the physical and socio-economic features that characterize the tank were studied. Some of the attributes that characterize the tank features were: a] the position of the tank (lower or upper catchment in the case of cascade);b] the mean annual rainfall and its variability; c] the ratio of catchment area to command area; d] percentage area of the tank catchment which is under cultivation; the density of wells in the catchment area & command area (in the case of cascade tanks), and command area in the case of others; and, e] the number of different types of existing uses of the tank. Comparing the values of the first set of performance indicators across tanks against the values of the attributes that characterize the tank features helped identify the physical and socio-economic settings under which tanks are likely to perform well.

Both primary data from tank user community and secondary data from minor irrigation department were used for this component of the study.

Objective IV:

Based on the above analysis (discussed for Objective III), the criteria for selection of tanks for rehabilitation was worked out. The basic premise was that those tanks which currently display or can in future display (after rehabilitation) those physical and socio-economic characteristics which are capable of ensuring good tank performance, as mentioned above, can be selected for rehabilitation. Subsequently, based on the analysis of exogenous factors that affect the performance of tanks and the way they influence, and the identification of physical and socio-economic characteristics that result in good tank performance, physical strategies for tank management and the institutional interventions were worked out.

CASE STUDY REGIONS

A total of six tanks from three districts of the state of Andhra Pradesh were chosen for the study, with two tanks from each district. The locations were chosen in such a way that each one represent a unique situation vis-à-vis the changes in historical performance of tanks. The districts are Vijayanagaram, Nizamabad, and Kurnool. Each one falls in a different river basin. Vijayanagaram falls in the drainage area of one of the east flowing rivers, north of Godavari river basin, which is a water rich river basin. Nizamabad falls in the drainage area of Godavari river basin, which again is a water-rich river basin. The area of Kurnool, which was chosen for the tank case studies, falls in the drainage area of Krishna river basin, which is a water-scarce river basin. Hence, each one represents one hydrological regime.

In Nizamabad district, as the district level data show, the area under tank irrigation, in terms of net tank irrigated area, had undergone dramatic reduction, over the past three and a half decades. In Vijayanagaram district, the area under tank irrigation had undergone some declining trend during the same period, but not as much as that of Nizamabad. In Kurnool district, no major reduction in area under tank irrigation was observed from the time series data for 35 years from 1970-71 t0 2004-05.

Within each district, the two study tanks were selected in such a way that one is in a better condition as compared to the other. The judgment about relative performance was made on the basis of the discussions with the officials of the irrigation and CAD department of the government of Andhra Pradesh, who were concerned with the management of these tanks. The criteria used for judging the performance are the condition of the tanks vis-à-vis the physical infrastructure, the area irrigated in the command area against the design command and the community involvement in their management.

Data Types and Sources

Data were collected from both primary and secondary sources. The primary data were collected both at the tank level and the farmer level. The tank level data included: the tank command area; the different uses of tanks and the number of HHs depending on the tank for various uses; area under different crops in different seasons and at different points of time (1970, 1980, 1990, 2000 and at present), and irrigated area under different crops in different seasons and at different points of time; number of wells in the tank command at different points of time; number of wells in tank catchment at different points of time; area under different crops in different seasons in the tank catchment, and irrigated area under different crops in different seasons at different points of time in the tank catchment. They were obtained from the village elders and tank water user association office bearers. The farmer level data consist of: i] area under different crops in different seasons, and at different points of time; ii] irrigated area under different crops in different seasons and at different points of time; iii] changes in cropping pattern and irrigated cropping pattern in drought year, normal year and wet year; and iv] the current sources of irrigation.

The secondary data comprises the net area irrigated by tank over the period from 1970-71 to 2005-06 in all the districts of AP; the net area irrigated by wells and bore wells over the same time period in all the districts of AP; the area irrigated by different sources viz., wells, tanks and canals in the state over the period 1970-71 to 2005-06; and the characteristics of tanks in different districts vis-à-vis their total water spread area, and the net area irrigated.

DESCRIPTION OF TANKS CHOSEN FOR CASE STUDY

Kurnool District

The geographical area of Kurnool is 17600 sq. km. The three revenue divisions in the district are Kurnool, Nadyal and Adoni divisions. Kurnool district includes 54 mandals and 920 revenue villages and 615 hamlets. The total population of Kurnool district as per Census 2011 is 40.4 lac (20.4 lac are male and 20.0 lac are female) with a population density of 200 /sq. km. The annual rainfall recorded from 2006 to 2010 are 600.8mm, 1082.2mm, 708.6mm, 767.9mm and 823.2mm, respectively.

Nallamalas and Erramalas are the two important mountain ranges in the district running in parallel from north to south. The Erramalas divide the district into two well defined tracts from East to West. This tract is crossed by the crest of Krishna and Pennar, watershed at the North part of the Pagidyala mandal at about 1000 m above the sea level. From this height the ground slopes to the South along the river Kundu till it traverses into Pennar valley. Major part of its tract is predominantly black cotton soils.

Table 1: Land Use Pattern and Agriculture in Kurnool District

Sr. No	Land Use	Area ha
1	Geographical area	1765800
2	Forest	340669
3	Barren and uncultivable	127313
4	Land put to non agricultural uses	138997
5	Cultivable waste	48074
6	Permanent Pastures	3576
7	Miscellaneous tree crops etc	1741
8	Current fallow	156859
9	Other fallow	78748
10	Net sown area	869823

11	Gross cropped area	1005966
12	Area sown more than once	136143

Source: Season and crop report Andhra Pradesh (2009 – 2010),
Directorate of Economics and statistics, Govt. of Andhra Pradesh, Hyderabad

Tank 1: Parumanchala MI tank, Parumanchala Village, Jupadu Mandal, Kurnool district

Parumanchala MI tank is located in the Parumanchala Village of Jupadu mandal in Kurnool district. The tank water users association was named as Parumanchala water users association in the year 1980. There are nearly 1200 tank beneficiaries from the 300 beneficiary households.

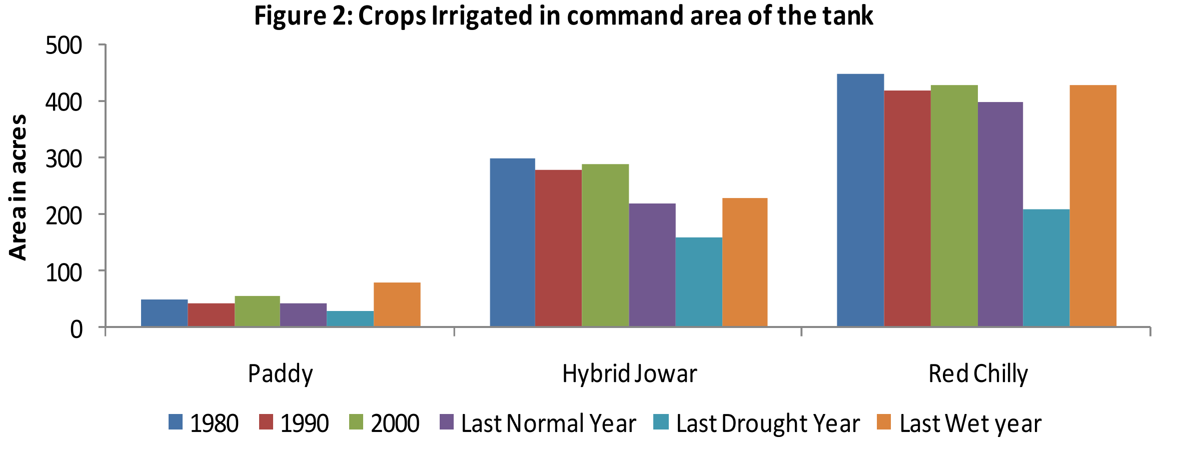
The total catchment area of the tank is nearly 91.8 Sq.km. Parumanchala tank has a water spread area of 288 acres and a command area of 1500 acres. The Sill/Bed level of the tank is 286m. Surplus weir has length of 174m. Some lifting devises were found in the dried portions of the tank bed. The farmers are lifting water from the tank to their crops through PVC pipes. In some cases the length of the pipe line was more than 4 km from the tank.

The total number of open wells increased from 3 in 1980 to 7 in 2011 in the tank catchment area. All the 7 open wells are functional. Similarly the total number of bore wells increased from 3 in 1980 to 6 in 2011. Today all the 6 bore wells are functional. At the time of survey, 3 lifting devises were seen near the command area of the tank along with PVC pipe lines to the fields. In the tank command area, 3 open wells and 2 bore wells are present which are functional.

During the last normal year, 300 households were deriving benefits for a] irrigation; b] water for livestock drinking; c] water for livestock washing; d] water for drinking and cooking; e] floor cleaning and washing utensils and f] for cloth washing, bathing and toilet use. For tank fisheries and collection of small fishes, 4 households are deriving benefits.

The crops irrigated in the tank command area are shown in Figure 2. Paddy, hybrid jowar and red chilly are the major crops irrigated under this tank command.

Figure 2: Crops Irrigated in command area of the tank



The fisheries operation is managed by a small community consisting of 20 beneficiaries.

Some of the species are *korameenu* and *pukka*. Shrimp and prawn are also raised in the tank. The annual beneficiary contribution for procurement of seeds, feeds etc in the last normal year was Rs. 45, 000. Total annual income from fisheries is around Rs. 50,000.

The tank was rehabilitated twice in the years 2005 and 2008. The tank rehabilitation works included a] restructuring of main irrigation/drainage channel; b] lining of main irrigation channel; and c] restructuring of tank sluices/weir. In the year 2005 nearly Rs. 4 lac was spent in tank rehabilitation works, by the minor irrigation department. The rehabilitation works were also implemented by the minor irrigation department. The same minor irrigation department spent around Rs. 5 lac in the year 2008 for the above said rehabilitation works.

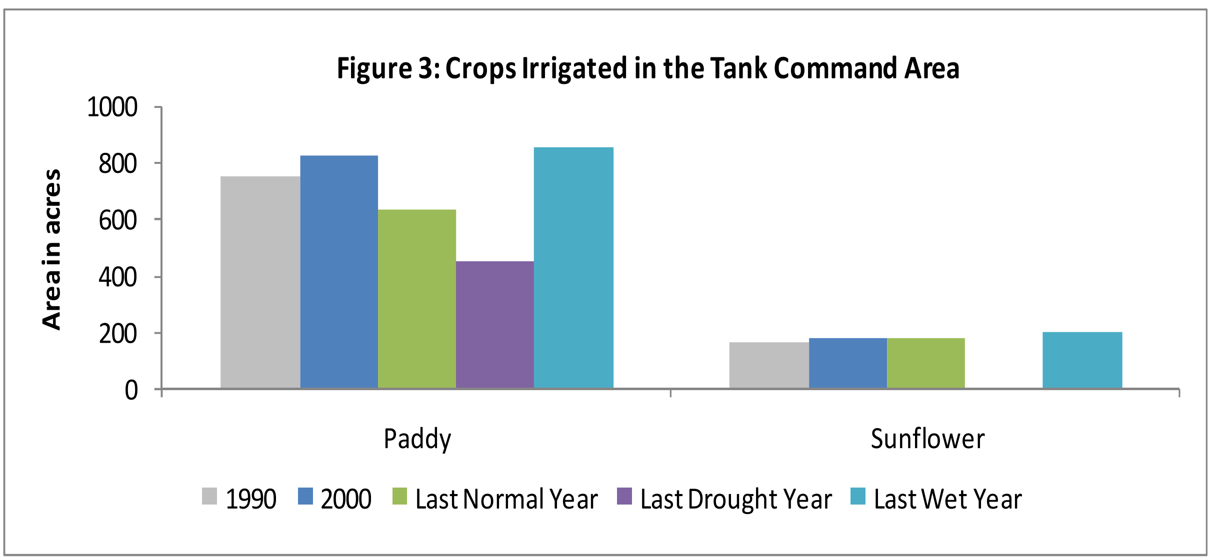
Tank 2: Padmaraja Tank of Indireswaram, Indireswaram Village, Atmakur Mandal, Kurnool district

Padmaraja tank is located in Indireswaram village of Atmakur mandal in Kurnool district. The water users association was named as "Padmaraja Water User Association" in the year 1988. The total number of beneficiary households under this tank is about 300 with nearly 1500 beneficiaries.

The total dependable yield of the tank catchment is 200 million cubic feet as per the MI records. The length of the bund is about 3270m. Padmaraja tank has command area of 850 acres. Catchment area of the tank is about 436 acres (number given by tank water user association President). From Figure 7 it is evident that a lot of jungle clearance is required. In the tank command area 16 functional open wells as present for the past 3 decades. One bore well is present in the tank command area which is also functional. No lifting devises were observed at the time of the survey.

About 250 households depend on the tank for irrigation for the past 3 decades. A group of 10 households depend on the tank for fisheries and collection of small fishes. All the households in the village (nearly 300 from Indireswaram village) derive benefits from the use of the tank for livestock drinking, livestock washing, water for floor cleaning and washing utensils, for cloth washing, bathing and toilet use.

Paddy and sunflower are the two major crops irrigated in the Padmaraja tank command area. The last normal, drought and wet years are 2011, 2010 and 2009 respectively (in Figure 3).



The fisheries operation is managed by a group of 20 people from 10 households. Koremeenu and pukka were the fish species cultivated in the Padmaraja tank in the last normal year. Apart from these fish species, prawns were also cultivated in the tank. The annual beneficiaries contribution for procurement of seeds, feeds etc was Rs. 50, 000 in the last normal year. Annual income from fisheries in the last normal year was around Rs. 55,000.

Padmaraja Tank was rehabilitated once in year 2008 by spending about Rs. 65 lac (sourced from MI department under World Bank Tanks Project). Panchayat implemented the works after receiving the above said money from the minor irrigation department. The rehabilitation works included: a] restructuring of main irrigation/drainage channel; b] lining of main irrigation channel; and, c] re-building of tank sluices/weir.

District Vizianagaram

The total geographical area of the district is about 6,300 km², which has a human population of 234286 as per 2011 census. About 51 per cent of the land area is sown area and another 12.3 per cent land is put to non-agricultural uses. The forest covers about 17.8 per cent of the land. Barren and uncultivable area constitutes about 12.3 per of the land and about 4 per cent of the land area is current and other fallow lands. The district is bounded by Srikakulam district on the east, Visakhapatnam district on the south west, the Bay of Bengal on the south east, and the State of Orissa on the northwest. The district can be divided into two distinct physiographic units, viz., plains and hilly regions. The hilly region mostly consists of hills covered by the Eastern Ghats which run parallel to the Coast from the North-East to South-West.

The principal rivers flowing in the district are Nagavali, Suvarnamukhi, Vegavathi, Champavathi, Gosthani and Kandivalasa. The climate of the district is characterized by high humidity nearly all-round the year with oppressive summer and good seasonal rainfall. The district receives both the South-West and North- East monsoon. The average annual rainfall is more than 700 mm.

There are total of around 1200 minor irrigation tanks in the district, with an *ayacut* or command area of about 51 thousand ha. Out of these, about 99 tanks were selected for rehabilitation under the World Bank supported community based tank management programme of Government of Andhra Pradesh. For the purpose of our study, we visited two irrigation tanks. The characteristics of each selected tank are discussed below.

1) Nalla Tank of Pinavemali

This tank is located about 20 km south of the centre of the town. The command and irrigated areas (kharif) of this tank are 325 acres and 300 acres respectively. Only Kharif paddy is taken in the tank command area. Most of the cultivable land in the ayacut is owned by small farmers. Though in technical terms, the tank is well functioning, it receives less water as there are other big functional irrigation tanks in the upper catchment, which impound the runoff and store. No water was found in the tank during the month of February, most of the water gets used by the month of October/November. Technical features of Nalla tank are given in Table 2.

Nalla tank is one of the most degraded tanks in Vizianagaram district. When visited during the hottest month of May in 2012, the tank bed was completely dry. The bund of the tank is very stable, with large number of matured palm trees. The tank has a large catchment, but is not hilly unlike Pedda tank. But, the catchment area is intensively cultivated with palm trees and field crops.

The tank receives very little inflows. During the summer months, the tank is completely empty. The command area of the tank is almost fallow during the summer months. There is only one well in the tank command, and the owner of this well grows sugarcane.

The village Panchayat had taken up digging of a pond inside the tank reservoir area under the NREGA scheme. The pond, which is already excavated, is around 100’ X 100’ X 3.5’. Discussion with some of the villagers revealed that the Panchayat had already spent nearly Rs. 20 lac for digging of this pond. The pond was dug for providing storage of water for livestock during the lean season. But, field verification indicated that the location of the pond is not at the lowest elevation in the tank bed so as to collect water when the water level recedes in the tank. Moreover, it was found that the dug-out soil was deposited around the periphery of the pond which would eventually block inflow of water from the reservoir area into the pond.

2) Pedda Tank of Rellivalasa

This tank is located about 20 km north of the centre of the town. The command area of *Rellivalasa* tank is about 600 acre. Like in the case of *Kumili* tank, there is a significant groundwater development in the tank ayacut. Farmers were found to be taking paddy in kharif; and maize and jowar in winter. Farmers were also found to be raising crops in the tank bed during winter. During the time of the field visit, water was available in this tank. Water from the tank is also used for livestock drinking and bathing; and other domestic (excluding drinking) uses.

Based on the observations made during the visit to the tanks; keeping in view the scope and objective of the research study; and logistic considerations, it was decided to select *Gopala Raju Tank* and *Nalla Tank* for the case study. It was also thought that subject to availability of time, one more tank i.e. *Pedda Tank of Rellivalasa* may also be selected. Detailed features of Nalla tank are given in Table 2.

Table 2: Salient Features of the Tanks Selected for the Field Study in Vizianagaram District

Sr. No	Details of Tank	Nalla Tank of Pinavemail (V), VIZIANAGARAM (M)
1	Length of Tank bund	1530.00 M
2	Top width of bund	3.00 M
3	Side slopes of bund	
	Front	1and 1/2 : 1
	Rear	2 : 1
4	No. of surplus weir	3 Nos.
	(a) Length of surplus weir No.1	13.40 M
	(b) Length of surplus weir No.2	23.80 M
	(c) Length of surplus weir No.3	21.35 M
5	No. of sluices	3 Nos.
	(a) Sill level of Sluice 1.	+ 29.88 M
	(b) Sill level of Sluice 2.	+ 29.99 M
	(c) Sill level of Sluice 3.	+ 29.92 M
6	Top of Bund Level TBL	+ 32.60 M

7	Max. Water Level MWL	+ 31.70 M
8	Full Tank Level FTL	+ 31.10 M
9	Ayacut Irrigated (or Irrigated area under tank)	310.09 acre
10	Volume of water stored	38.76 mc ft
11	No. of fillings	2 fillings
12	Catchment area	1.97 sq. miles
13	Water Spread area	NA
14	Location of Tank	
	Latitude :	Latitude : 83^{*}-$19^{\prime}$-$28^{\prime\prime}$
	Longitude :	Longitude:18^{*}-$5^{\prime}$-$36^{\prime\prime}$

Source:

Pedda tank of Rellivalasa is located about 20 km north of Vizianagaram district head quarter in Poosapatrega mandal. The Pedda tank of Rellivalasa water users association was formed in the year 2006 with nearly 1000 tank beneficiary households in the village. The command area of the tank is nearly 750 acres. The catchment (around 1275 acres) is mainly covered by hills, which are part of the Eastern Ghat and still there is some amount of inflow during the monsoon from the catchment. This is because, the chances of catchment cultivation is extremely poor. Three sluices were constructed in the tank with 2 surplus weirs. The length of the bund is about is more than 1000 m.

Pedda talk is one of the comparatively less degraded tanks in Vizianagaram district. The tank has a command area of around 1,200 acres. There were a total of 64 functional wells in the tank command in the year 1970 and 60 wells in the current year (2011). In 1970s nearly 15 functional wells were present in the tank catchment area. The number of functional wells came down to 6 in the year 2000. Several wells have come up in the tank command during the last decade. The average area irrigated by the bore well is nearly 3 acres, according to the farmers in the command. The irrigation is mainly for the winter crop of maize, which is a low water intensive crop. Some irrigation is supplied to the short duration summer crops from bore wells. The power supply is only for 7 hours in the area.

There is some area under cultivation in the tank bed during summer months, which uses water from the tank through the use of pump sets. It could be reasonably argued that intensive well irrigation is one of the reasons for degradation of this tank. The excessive withdrawal of water from the bore wells increases the percolation of water from the tanks, thereby reducing its irrigation potential.

One of the interesting features of the command area of the tank is the presence of several homesteads. All these homesteads have coconut plantations along with other fruit trees, especially mangoes. Coconut is also grown along the boundaries of several of the farms. Presence of coconut plantation is indicative of relatively high water availability in the area. Palm is another major tree crop in the area.

Nearly 800 households were deriving benefits from the tank use for irrigation in 1970s. In the current situation (2011) more than 750 households derive benefits from the tank uses for irrigation. During the last normal year (2011) about 60 families were deriving benefits from the tank for fisheries and nearly. For collection of small fishes more than 350 households depend on this tank in the current situation. About 800 households use the tank water for livestock drinking (2011). It was learnt at the time of survey that nearly 200 families in the village use the tank water for cloth washing, bathing and toilet use.

Today, the farmers in the command take three crops, viz., paddy, maize and sesame. Paddy is the kharif crop, and is irrigated with tank water. At the same time, maize, which is the winter crop, is irrigated with well water. Sesame, though sown during the hottest month of May, requires very little irrigation, owing to the onset of monsoon by the first week of June. The irrigation water requirement of this crop is met from bore wells in the command. Figure 4 show the percentage area under different crops in the tank command area over the years starting from 1970. Figure 5 shows the variation in cropping pattern between a wet year and dry year, at present. As expected, during wet year, percentage area under winter maize increases, and back gram, which generally survives on residual soil moisture from harvested paddy fields, is not cultivated during the season in wet years. During summer, the farmers cultivate sesame (til). The crop is harvested in July, soon after which paddy is sown.

Figure 6 shows the percentage change in irrigated crops during the period from 1970 to 2000. As is evident, the percentage area under black gram has been on the rise, though during the last normal year (2011), it declined to around 18.3 per cent. The irrigated cropping pattern also shows similar trend as cropping pattern, in terms of what farmers prefer during wet years. The area under irrigated maize is as high as 43.5 per cent of the gross irrigated area, which can be attributed to relatively abundant water supply. Figure 7 shows the variation in percentage area under irrigation between a wet year and dry year, at present.

Figure 4: Percentage Area under Different Crops in the Pedda Tank Command (1970 - 2000)

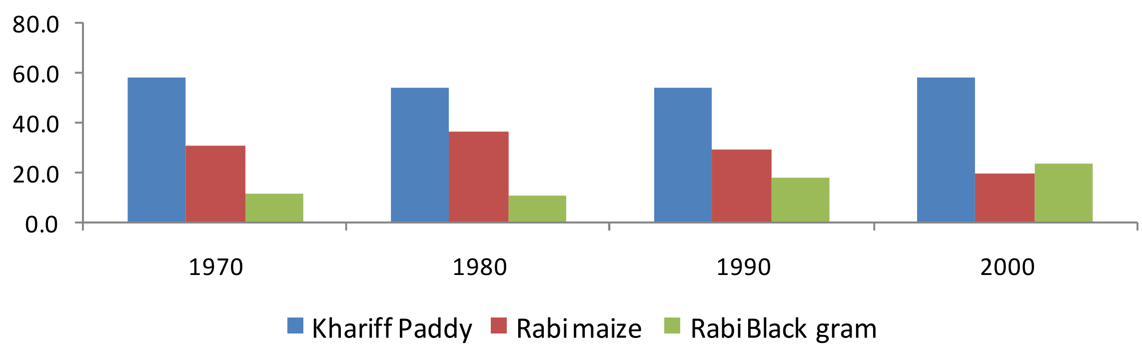


Figure 5: Percentage Area under Different Crops n Pedda Tank Command
(Current Situation)

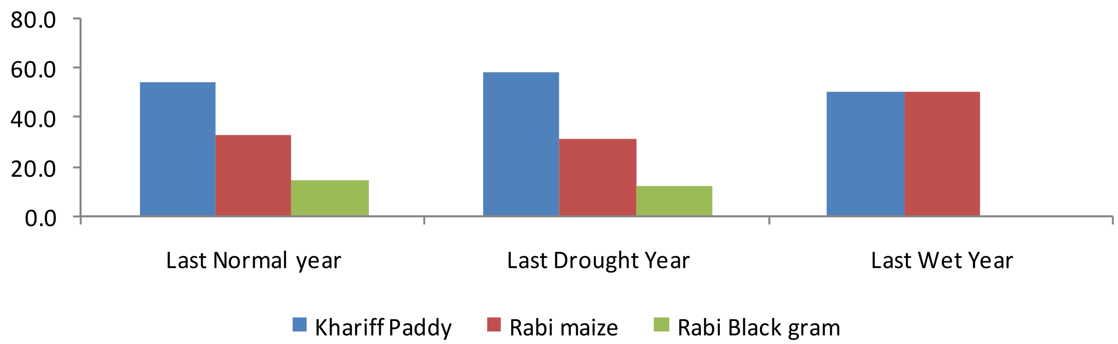


Figure 6: Percentage Irrigated Area in Pedda tank Command
(1970 - 2000)

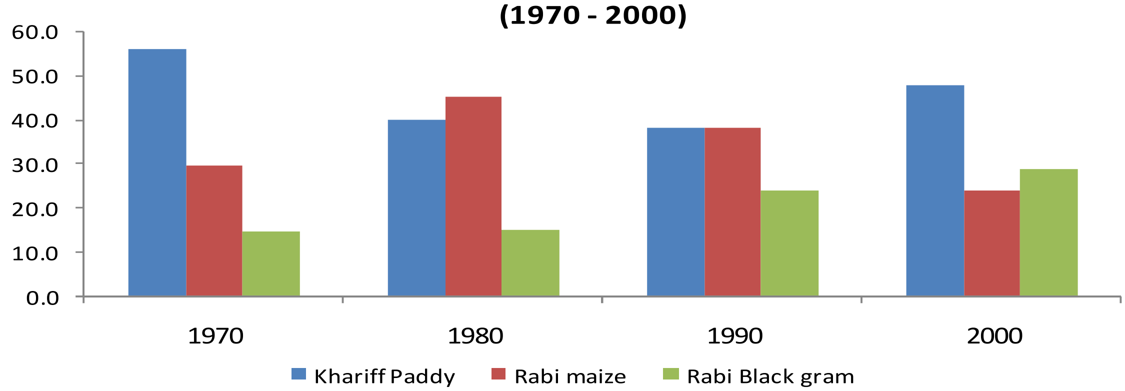
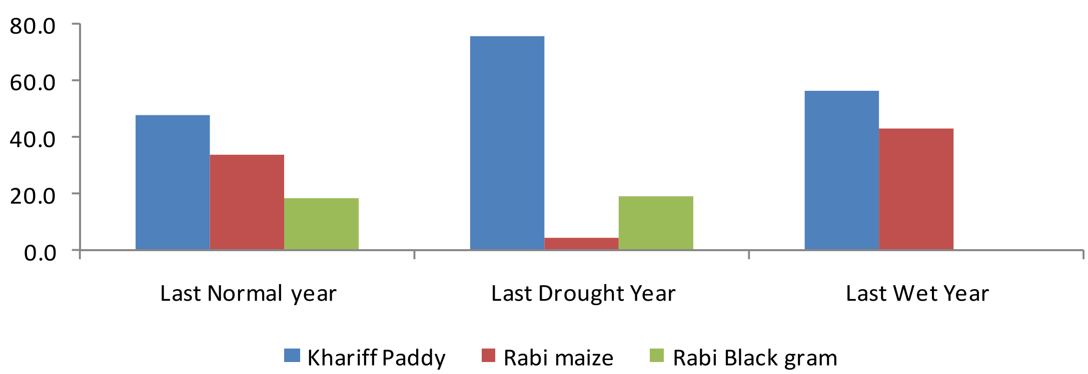


Figure 7: Percentage Irrigated Area in Pedda tank Command
(Current Situation)



The fisheries operation is managed by community with nearly 120 beneficiaries. The annual beneficiary contribution for procurement of seeds, feeds etc during the last normal year was (2011) about Rs. 50,000. The total income from fisheries in the last normal year was Rs. 2.5 lac. The species cultivated in the tank are Mrugal, Indian Major Carp and Indian common carp.

The Pedda Tank of Rellivalasa was rehabilitated twice, once in the year 2000 and once in 2011. In the year 2000 the tank was rehabilitated by PWD (MI). Nearly Rs. 80, 000 was spent by the MI department and the money was sourced from the state Government. The rehabilitation works included sluice repair and de-silting (small part) which was implemented by the MI department.

Later on in 2011, the tank rehabilitation works were carried out by water users association by making use of fund from NREGS. The rehabilitation works included de-silting, cleaning of supply channels. Nearly Rs 10 lac has already been spent by the end of last normal year.

Nizamabad District

The geographical area of Nizamabad District is 7956 sq. km. There are three revenue divisions in the district viz., Nizamabad division, Bodhan division and Kamareddy division. Nizamabad district includes 36 mandals and 922 villages. Total population of Nizamabad district as per 2011 census is 25.52 lac (12.52 lac are Male and 13.00 lac are Female). Population density is 321/sq. km. The normal rainfall (district average) is 1035.5mm. Actual rainfall values recorded in the past 6 years are 1170.7mm, 962.1mm, 961.5mm, 840.5mm, 688mm and 1044.4mm respectively. Similarly the percentage deviations in the normal rainfall against actual rainfall are 13.1, -7.1, -7.1, -18.8, -33.6 and 3.9, respectively. Table 3 presents the land use pattern and agriculture in the district.

Table 3: Land use in Nizamabad District

Sr. No	Land Use	Area lac ha	% Area
1	Geographical area	7.95	
2	Forest	1.69	
3	Barren and uncultivable	0.47	
4	Land put to non agricultural uses	0.88	
5	Cultivable waste	0.15	
6	Permanent Pastures	0.24	
7	Miscellaneous tree crops etc	0.03	
8	Current fallow	1.19	
9	Other fallow	0.74	
10	Net sown area	2.56	
11	Gross cropped area	4.10	
12	Area sown more than once	1.54	

Source: www.nizamabad.nic.in

Table 4: Area irrigated by Different Sources (2005-06 to 2009-10) in Ha in Nizamabad District

Sl. No.	Source of Irrigation	2005-06	2006-07	2007-08	2008-09	2009-10
1	Canals	21199	50756	17259	50355	213

2	Tanks	24757	21286	7214	14780	4667
3	Tube Wells & Filter points	219053	215302	244621	246486	227934
4	Other Wells	8159	7560	8296	8981	5247
5	Lift Irrigation	6393	7225	7961	9519	3780
6	Net Area Irrigation	158124	174298	169840	186213	134544
7	Gross Area irrigated	279561	302129	285351	330121	241841
8	Area irrigated more than once	121437	127831	115511	143908	107297

Source: www.nizamabad.nic.in

Tank 1: Jukkula Tank, Bhavanipet Village, Machareddy Mandal, Nizamabad District

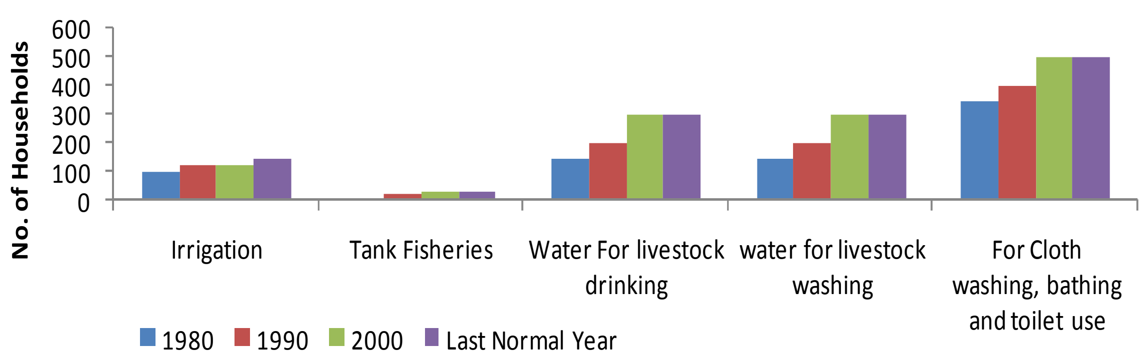
Jukkala Tank is located in Bhavanipet village of Machareddy Mandal in Nizamabad district. The name of the tank water user association formed in the year 1999 is "Jukkula Cheruvu Saguneeti Sangham". About 500 households (1800 beneficiaries) in Bhavanipet village derive benefits from this tank. This tank is not the part of a cascade system.

The catchment area of the tank is about 500 acres. The command area under this tank is about 160 acres. The total capacity of the tank as per the official records is 10.454 MCft. Bund length of the tank is 630m. One sluice and a waste weir were constructed for this tank. Figure 1 and 2 represent the tank and the command area.

Data from the field survey shows that over the years, many open wells and bore wells were installed both in the tank command and catchment areas. As on 2011 about 120 open wells were present in the command area and 350 open wells were present in the tank catchment area. None of these open wells are functional. It was also observed that out of 30 bore wells in the command area only 10 were functioning as on 2011. Similarly, in the tank catchment area 15 bore wells are functional out of 30 bore wells installed as on 2011. At the time of survey, no lift devises were present in the catchment / command area of the tank.

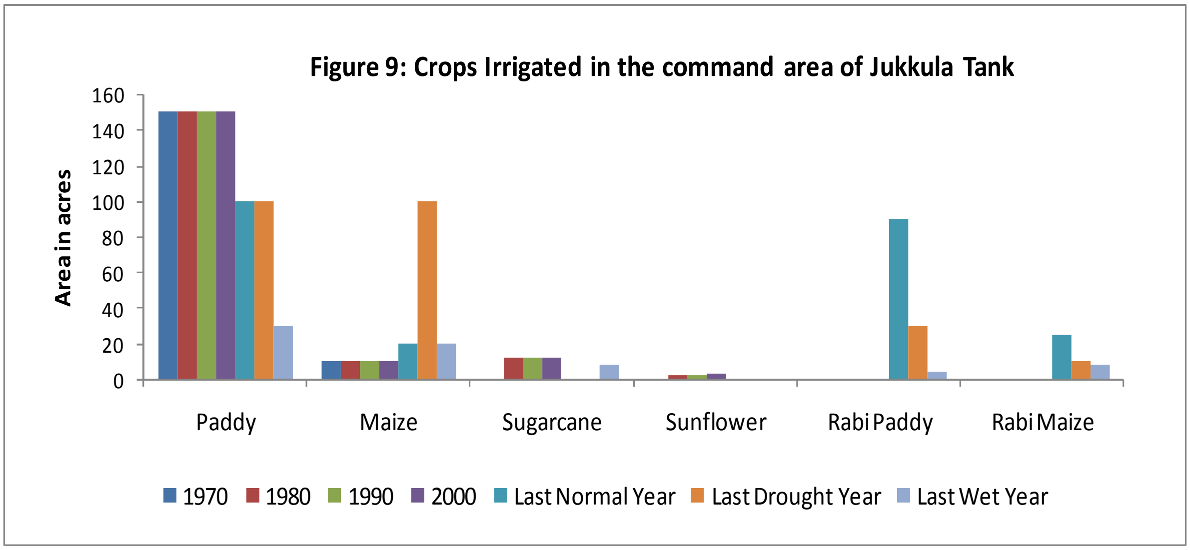
The number of households which are depending on the tank for various purposes increased over the years from 1980s to 2011. From Figure 8, it is also evident that more number of households are driving benefits from the use of the tank for cloth washing, bathing and toilet use, when compared to other uses like irrigation and tank fisheries.

Figure 8: No.of HHs driving benefits from the use of the Tank (in command area)



Source: Secondary Data Collected from Jukkula Tank Water Users Association

Figures 9 and 10 represent the irrigated crops in the command area and the catchment area of the tank, over the years.

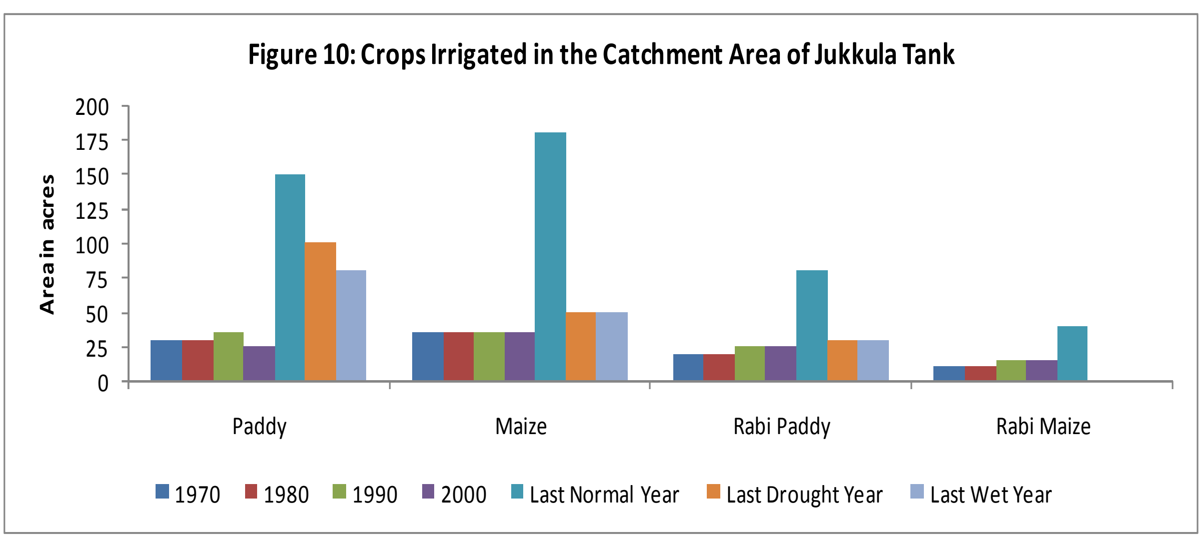


The fisheries operation in the tank is managed by the community (Gundla Sangham) with 20 beneficiaries. Indian Major Carp, Catfish are some of the fish species in the tank. The annual beneficiary contribution for procurement of seeds, feeds etc was Rs. 1, 00,000 and Rs, 80,000 in the last normal and drought years respectively. The duration of fisheries in a year is generally for 8 months. The total annual income from fisheries was Rs. 1, 20, 000 and Rs. 1, 00, 000 in the last normal and drought years respectively.

The tank was rehabilitated 4 times in the past in the year 2010. The nature of rehabilitation works include a] restructuring of main irrigation / drainage channel, b] restructuring of tank sluices / weir, and 3] de-silting / cleaning of main irrigation channel. About Rs. 3, 00, 000 sourced from NREGS and Panchayat programs, was spent for the tank rehabilitation in 2010 along with community contribution to an extent of Rs. 1, 00, 000. These rehabilitation works were implemented by Panchayat, Tank water User Association and NGOs.

At the time of primary survey, it was observed that a major portion of the tank needs jungle clearance and de-silting.

Tank 2: Gundla Tank of Domakonda, Domakonda Village and Mandal, Nizamabad District

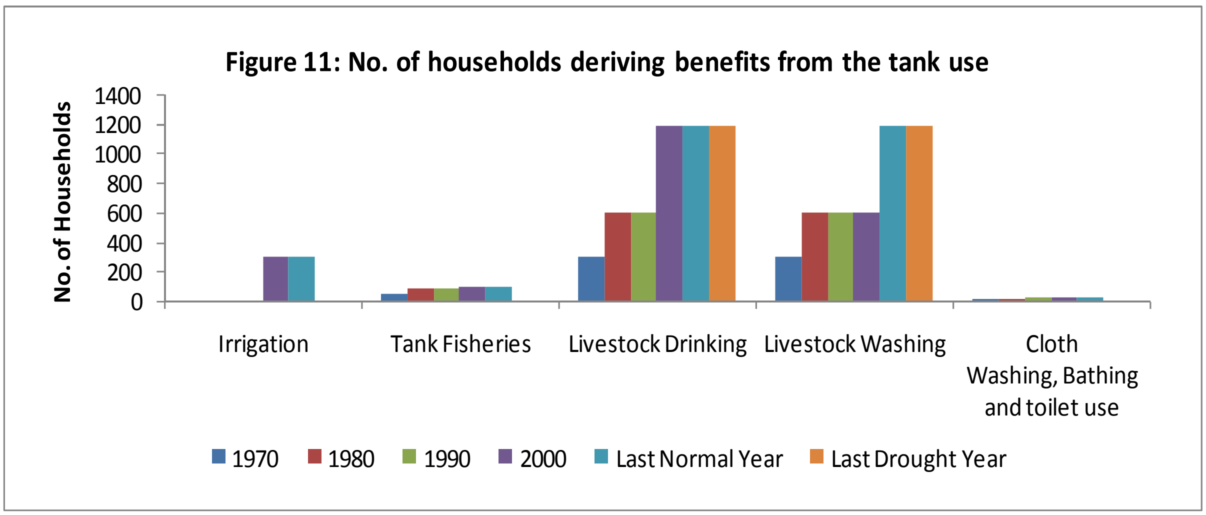


Gundla Tank is located in Domakonda village of Domakonda Mandal in Nizamabad district. The tank water users association was formed in the year 1997 which was named as "Gundla Cheruvu *Saguneeti* Sangham". About 1000 households (nearly 6000 beneficiaries) derive benefits from the Gundla tank. The Gundla tank is physically in good condition when compared to Jukkula Tank of Bhavanipet.

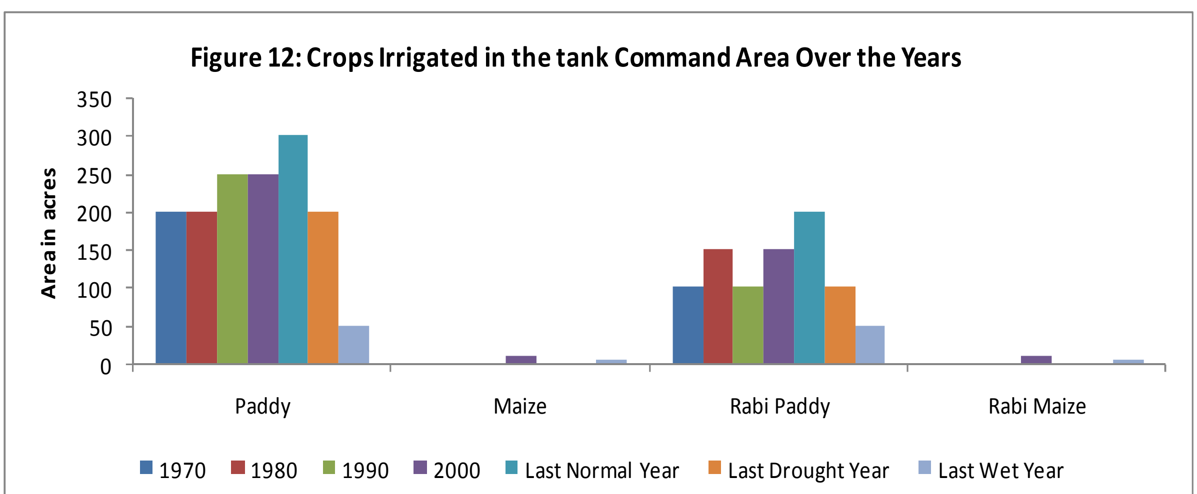
The catchment area of the tank is approximately 600 acres. The command area of the tank is about 302 acres. The total capacity of the tank as per the official records is 23.0 million cubic feet. Bund length of the tank is 1020m.Three sluices were constructed for this tank.

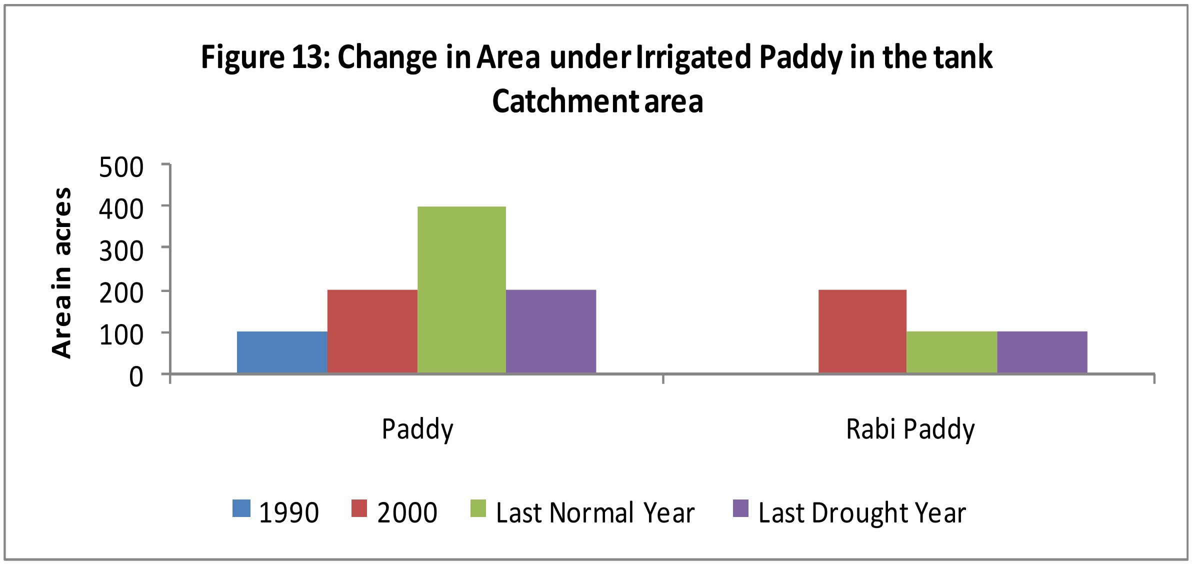
As on 2011, about 300 open wells were present in the tank command area and none of these wells are functional today. Nearly 30 bore wells are present in the tank command area, out of which 25 are functional. The numbers of bore wells functioning were only 6 in the year 1990 which increased to 25 in the year 2011 (increased by more than 4 times).

The number of households deriving benefits from tank fisheries increased from 50 in the



year 1970 to 100 in the last normal year. Figure 11 as shown below gives an idea of other benefits derived by the households over the years.





The fisheries operation in the Gundla Tank is managed by a community called *Mudiraj* sangham in Domakonda village. About 5 species of fishes are cultivated in the tank. Some of them are Indian Carp, Catfish. The duration of fisheries operation in a year is about 10 months. Nearly 30 beneficiaries derive benefits from the tank for fish. The annual beneficiary contribution for procurement of seeds, feeds etc during last normal and drought years is Rs. 1, 00, 000. The annual income from fisheries during last normal year was Rs 1, 80, 000 and nearly Rs. 1, 20, 000 during the last drought year.

Gundla Tank was rehabilitated once in the year 2000 and 4 times in the year 2010. The rehabilitation work mainly included lining of main irrigation channel in the year 2000. For this tank rehabilitation work, about Rs. 1.0 lac was spent by the State Government. The rehabilitation work was implemented by the tank water users association. The rehabilitation works undertaken during 2010 included a] restructuring of tank sluices/weir and b] de-silting/cleaning of main irrigation channel. Total amount spent on this rehabilitation was nearly Rs. 2, 50, 000 which included 60% contribution from NREGS and about 40% contribution from Panchayat programmes. The works were implemented by Panchayat, tank water users association and NGOs.

RESULTS AND DISCUSSION

Tanks in Andhra Pradesh

Tanks are manmade wetlands as per wetland classification. Out of the total of 18,701 manmade wetlands in the state of Andhra Pradesh, with wetland area less than 2.5 ha and covering a total wetland area of 610354 ha, 15,290 are tanks/ponds constituting a total wetland area of 1.4lac ha. The rest are man-made reservoirs, water logged areas etc. The state has three distinct physiographical units. First is the coastal plain to the east extending from the Bay of Bengal to the mountain ranges; Eastern Ghats which form the flank of the coastal plains; and plateau to the west of the Eastern Ghats. Maximum tanks are found in the plateau. The district-wise number of tanks, their wetland area, and the water-spread area pre and post monsoon are given in Table 5.

Table 5: Number of Tanks and their Wetland Area in Different Districts of Andhra Pradesh

Sr. No	Name of District	Total number of Tanks/ Ponds	Total Wetland area (ha)	Average Wetland Area per Tank/ Pond (ha)	Total water spread area (ha)	
					Post-monsoon	Pre Monsoon
1	Adilabad	590	7383	12.51	5090	1947
2	Nizamabad	915	19152	12.51	13581	7629
3	Karimnagar	692	10535	20.93	8802	3590
4	Medak	1066	20116	15.22	16250	8011
5	Hyderabad	12	107	18.87	71	73
6	Rangareddy	281	3287	8.92	2728	2002
7	Mahbubnagar	340	5424	11.70	3509	2510
8	Nalgonda	601	11702	15.95	8573	5857
9	Warangal	659	9462	19.47	8433	2367
10	Khammam	558	8044	14.36	5547	2762
11	Srikakulam	460	4678	14.42	3260	1459
12	Vijayanagaram	1539	10567	10.17	7724	2293
13	Visakhapatnam	543	4793	6.87	3409	1341
14	East Godavari	505	4244	8.83	3384	2764
15	West Godavari	334	3191	8.40	2409	1808
16	Krishna	511	6312	9.55	4452	2418
17	Guntur	377	3512	12.35	2678	1939
18	Prakasam	480	7490	9.32	5918	3572
19	Nellore	1088	27673	15.60	24890	7151
20	Cuddappa	220	3584	25.43	3069	1458
21	Kurnool	142	1887	16.29	1395	810
22	Anantapur	447	9896	13.29	3131	4135
23	Chittoor	1391	18638	22.14	17200	3560
24	**Total**	**15290**	**212244**	**13.88**	**163227**	**73749**

Source: Authors' own estimates based on National Wetland Atlas, Andhra Pradesh prepared by Indian Space Research Organization, Ahmedabad.

What is most interesting is the fact the water spread area of these wetlands shrinks drastically after the winter, touching the lowest point during peak summer. Table 1 shows that summer water spread area (73,749 ha) is less than half of post monsoon, i.e., November, 2010 (1632277 ha). This has major implications for the total water availability of these tanks and the various functions that these tanks can perform in different seasons. Comparison of district-wise data shows that Vijayanagaram has the largest number of tanks, followed by Nellore and Medak. But, in terms of average size, tanks/ponds in Cuddappa are the largest, with an area of 25.40 ha.

Another interesting observation is that the ratio of the area irrigated by the tank and the wetland area, which reflect the physical characteristic of tanks, vary widely between districts. For the analysis, we have considered the area irrigated by the tanks in 1970-71, assuming that the real deterioration in tank performance started only later. The wetland area (as estimated through remote sensing imageries) of the tank was taken from the Wetland atlas prepared by the Indian Space Research Organization, Ahmedabad. Since the estimates of wetland area do not consider the tanks with wetland area less than 2.5 ha, it might induce some errors in the estimation of irrigated area-wetland area ratio. The ratio varies from 2.62 in the case of Medak to 23.47 in the case of Srikakulam. Here, Gunter was not considered for the analysis owing to the fact that the tanks in this coastal district receive water from large irrigation schemes. Hyderabad was also not considered as data on tank irrigation in the district was incomplete.

Ongoing Programmes of Tank Management in Andhra Pradesh

The Irrigation and CAD department of the Government of Andhra Pradesh had undertaken an ambitious programme for rehabilitation of tanks coming under the minor irrigation department, which have design command area of more than 100 acres. It is to be mentioned here that those tanks which have less than 100 ha of design command area are under the jurisdiction of Panchayats. The programme funded by the World Bank, called Andhra Pradesh community based tank management project, envisages rehabilitation of 3,000 minor irrigation tanks covering 21 districts of the state. The technical or engineering interventions under the rehabilitation programme include de-silting, jungle clearance, stabilization of bund, sluice repair, waste-weir construction or repair.

As per the project guidelines, the planning, implementation and post construction operation and management of the project are to lie with the water users' associations. Software inputs include training of water users associations for capacity building. To facilitate the planning, implementation and post implementation management of various tanks associated with tank rehabilitation, there would be one support organization at a level of a cluster of 5-10 tanks.

One of the positive features of the programme is that it is demand driven. The type of activities to be undertaken for rehabilitation of tanks for restoration of irrigation in the command area is to be decided by the water users' association. The funds allocated for this, i.e., Rs. 25,000 per ha of design command area, appears to be quite sufficient at current prices, given the fact that this is for retrofitting of an already built irrigation infrastructure, and not for building new ones. Again, the programme has inbuilt checks and balances for technical soundness and financial management. The plans prepared by the Water Users' Associations are scrutinized by the technical staff of the minor irrigation department after field visits, and they prepare detailed project report with the estimates for the planned works subsequently. There is a technical manual, which provides the guidelines for design and execution of the physical works, and system operation[1].

[1] The manual clearly specifies the guidelines on engineering design, construction and quality control for the physical components of the work. It also clearly specifies the standards that need to be maintained for each of the tank constituent be it concrete work, earth work, reinforcement, stone masonry work, revetments, protection of upstream and downstream works and canal lining.

As the department slightly deviates from its usual operations for this project and added several new activities as the project components, a separate financial manual was prepared exclusively for implementing this project. This document describes the procedure for fund flow and arrangement at the state, district and WUA level, budget preparation, financial management systems at various levels. The manual also provides procedure for fund disbursement and accounting system that will be followed in the project. One important financial innovation used in the project is that any expenditure for rehabilitation work below Rs.50000 could be sanctioned by an officer in the rank of Assistant Engineer, and any expenditure in the range of Rs. 50,000-Rs.200000 could be sanctioned by a Deputy Engineer or Deputy Executive Engineer.

Another notable innovation is with regard to the repayment of water charges being collected from the tank users. Though the cess is collected by the revenue department office at the Mandal level, arrangements are made for quick release of a major share of these funds back to the Water Users' Association through the concerned section office of the irrigation department. This keeps big incentive for the WUA to motivate the member farmers to clear their water dues timely. These funds are to be used for small repair works.

It appears, from a careful scrutiny of the documents relating to the tank management project, that a clear cut protocol for picking up tanks for rehabilitation is absent. There was no clear cut policy on the part of the department, which could have been used as the guideline for short-listing the 3,000 tanks for rehabilitation, among the many thousands of tanks/ponds in the state. The proposal for the tank management project was prepared on the basis of the feedback and suggestions given by the technical officers (engineers) of the department who are concerned with management of minor irrigation tanks, from the districts and mandals concerned. One quantitative criterion used by the department was to take only those which have a command area of more than 25 ha (i.e., 100 acres). The second criterion was presence of some local initiative by the community for tank management. This, however, was purely based on perception. While this shortcoming could have been overcome through a prudent attempt by the department to involve the local tank communities in this key decision making, there was no involvement of the tank community whatsoever in selecting the tanks for rehabilitation.

Perhaps, one important consideration which was totally missing in the entire selection process is the hydrological condition of the tanks. Very little attention is paid to the fact that several external factors such as the intensive use of groundwater, catchment encroachment for cultivation are ruining the potential of tanks as reliable sources of water for multiple needs, including irrigation, through their effect on hydrology, which is mostly irreversible[2]. Sufficient efforts are not being made to ensure that the tanks chosen for rehabilitation get sufficient inflows from its catchment. This is also evident from the procedure followed for estimating the catchment runoff, one important variable for deciding on the capacity of the tank. The agency appears to be using the "rational formula" for estimating the catchment runoff on the basis of the total catchment area and a runoff coefficient fixed on the basis of the dependable rainfall (for 75% dependability). This is a very crude method of runoff estimation. The problem is that for semi-arid regions with low to medium rainfalls occurring in an erratic fashion, and for the land cover that exist, the runoff will not be a linear function of the annual rainfall magnitude, but will increase with rainfall in an exponential fashion. Hence, assuming a fixed value for runoff coefficient will lead to a major error in estimation of runoff.

[2] For instance, it is impossible to stop groundwater exploitation in the catchments and commands. In rural contexts, it is also impractical to clear the encroachments from the catchments.

Ideally, the runoff coefficient will be very low for low rainfall and disproportionately high for high rainfall in semi arid regions with high aridity (Prinz, 2000) causing high variability in runoff (Kumar *et al*. 2006; Kumar *et al*., 2008). Therefore, the runoff needs to be estimated on the basis of the rainfall-runoff relationship established for the basin or the sub-basin in which the tank catchment falls. This can be done using historical data on stream-flows and precipitation for the basin/sub-basin under consideration. Once the rainfall-runoff relation (model) is established, the stream flows for the years (for which records are not available) can be computed on the basis of observed rainfall. From these stream-flow values (say for 30-50 years), the dependable runoff (for 75% dependability) can be estimated and used for planning the rehabilitation work. This has to be the most crucial input for deciding on the types of uses from the tank and the cropping pattern.

In view of the many changes happening in rural landscape including the drainage interception, there is a need for re-assessing the catchment area of the tanks. In the absence of this, there is a very high chance that the catchment and therefore the runoff get over-estimated. The current hydrological planning is flawed, often leading to over-estimation of the tank size, and excavation work.

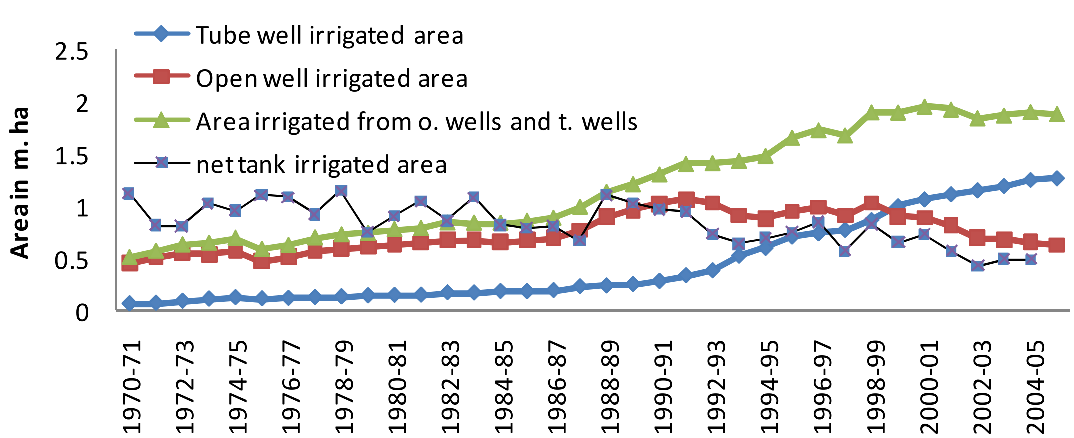
Impact of Well Irrigation on Tank Hydrology

It was hypothesized in the beginning of our research that increase in groundwater use in the catchment and command of the tank would affect the performance of the tanks, through reduction in the inflows into the tank in the form of groundwater outflows or base flows in the streams.

Naturally, base flow contribution to tank inflows would be significant in the case of tanks situated in the upper catchments of river basins, by virtue of the hilly topography and the forested catchments. One example is the tanks located just downstream of the forested catchments of Krishna river basin in Kurnool district. These upper catchment tanks are surrounded on three sides by protected forest area, with good base flows coming in from them. Though in such areas the chances of intensive groundwater use is quite low due to the poor availability of arable land and extremely low groundwater potential in the hard rock formations in the hills, even a small increase in groundwater pumping could alter the hydrological balance.

On the contrary, in the lower catchment tanks, the contribution of base flows to tank

Figure 14: Net area irrigated by o. wells, tube wells and tanks, AP



inflows could be quite low, and the major contribution of the tank inflows would be from the surface runoff. In these areas, the change in land use is the most important factor altering the tank hydrology. The net area under cultivation in these areas is likely to have increased due to increased pressure on land. Here, in this case, it is not an expansion in area under irrigation which is causing changes in the tank hydrology, but increase in area under cultivation. Mostly, it is resulting from encroachment of the common land, which forms the tank catchment, by villagers for cultivation of rainy season crops, which is causing the change.

While normally a part of the rainwater falling in the natural catchments would infiltrate into the soil and the remaining water would run-off from the land. While part of this infiltrating water would remain in the soil profile depending on the soil storage capacity, the excess water would percolate down the soil strata and join the groundwater table. The water in the soil profile would eventually evaporate if the soil is barren or else it would support the growth of some natural grass species. But, in any case the rate of evaporation of moisture from the soil profile would be very low. Whereas, once the land is covered by crops, the rate of depletion of moisture from the soil profile would be faster, as the crop would take the water for meeting the transpiration needs. While this would create more storage space in the soil profile for the incoming precipitation, the presence of vegetation would increase the rate of infiltration. The presence of field bunds would further reduce the downward movement of runoff generated in the field, and the water would percolate down the soil if it is in excess of the moisture deficit in the crop root zone.

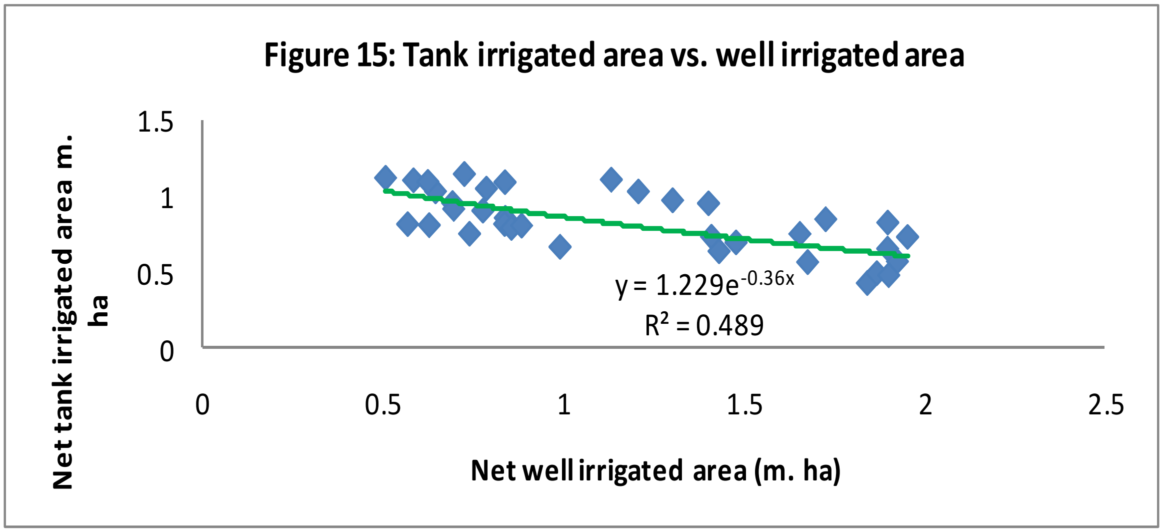
In order to understand the dynamics of interaction between tank catchment, groundwater and tank hydrology, we began with the analysis of time series data on net area irrigated by tanks, net area irrigated by open wells and tube (or bore) wells. Historical data on net area irrigated by tanks, open wells and tube wells/bore wells for the period from 1970-71 to 2004-05 are analyzed. The results showing the historical changes in the irrigated area from these three sources are presented in graphical form in Figure 14.

Figure 14 shows that while the area irrigated by open wells increased till the mid eighties and touched the peak in 1990-91, and started declining thereafter. Whereas the area under tube wells/ bore wells, which tapped the deeper aquifers and geological formations, started increasing exponentially by early 90s and continues even today. Overall, the area irrigated by wells has been increasing till 2000-01, when it peaked at 1.95 million hectares.

On the other hand, the (net) area irrigated by tanks started consistently showing declining trends after the late 80s. Though there has been wide fluctuations in the net area irrigated by tanks between years during the previous years, i.e., 1970-71 to 1987-88, such fluctuations could be attributed to inter-annual variability in rainfall, which will have direct impact on tank inflows. Regressions run between net tank-irrigated area and net well irrigated area,--the sum of area irrigated by open wells and tube wells--, showed a strong inverse relation the two, With increased in well irrigated area, the area irrigated by tanks reduced linearly (R^2=0.49) (Figure 15). Further, regression was run with net tank irrigated area against area irrigated by bore wells. This showed a sharper and stronger relationship (Figure 16). Going by the regression formulae, a unit increase in net tube/bore well irrigated area resulted in greater reduction in tank irrigated areas, as compared to that caused by unit increase in net total well irrigated area. Also, the increase in tube well/bore well irrigation explained reduction in tank irrigated area to an extent of 63 per cent, against 49 per cent in the case of total well irrigated area (Kumar *et al*., 2011).

The differential trends can be explained in the following way. Increase in well irrigation resulting from increased withdrawal of water from open wells and bore wells, suggests greater withdrawal of groundwater. This would normally affect the base flows into tanks, and also the percolation of stored water in the tanks into the formations underlying it, depending on where the tanks are located within the basin. But, at the same time, consistent increase in area under well irrigation till around the year, 1991-92 can also be suggestive of the fact that un-sustainable levels of abstraction of the shallow aquifer were not reached till that point of time. Under such circumstances, the effect of groundwater withdrawal on tank inflows will be less. This explains the milder slope of the curve representing decline in tank irrigation with increase in well irrigation.

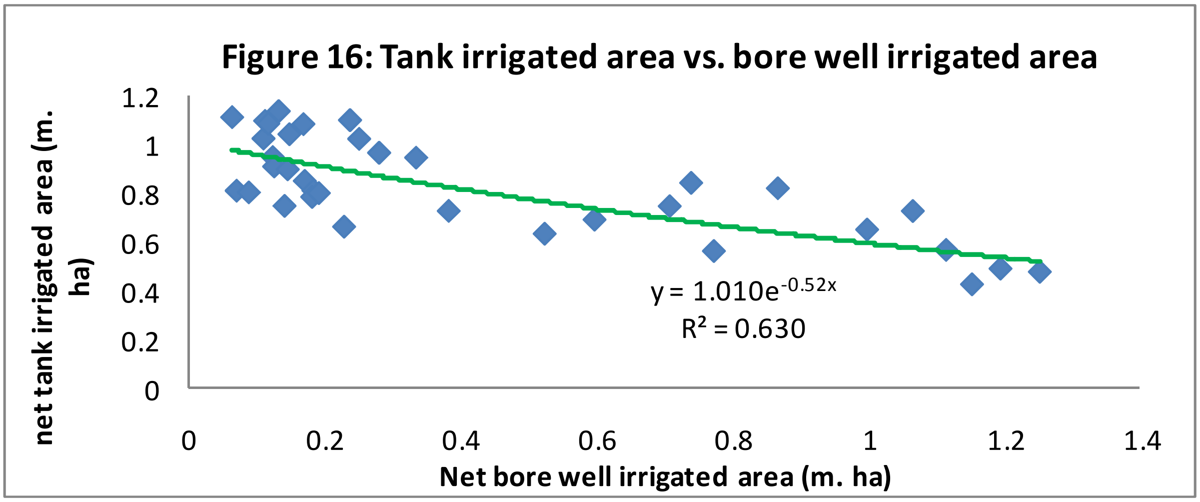
Now as regards the lower regression value, other than well irrigation, rainfall can also be an important factor which explains the changes in tank irrigated area. In good rainfall years, the tank



inflows, including that from groundwater outflows or base flows, could also be high, especially when the open well irrigation is still dominant. Nevertheless, there would be rise in pumping above the normal year values as a result of better replenishment of groundwater. In contrast, in low rainfall years, the runoff and base flows could reduce, along with groundwater recharge. So, in such years, the groundwater irrigation from open wells along with tank irrigation would be less than that of normal year values. This would upset the normal trend. Such trends in well irrigation, which is characteristic of hard rock regions with poor static groundwater resources, are visible in Andhra Pradesh (see Figure 14).

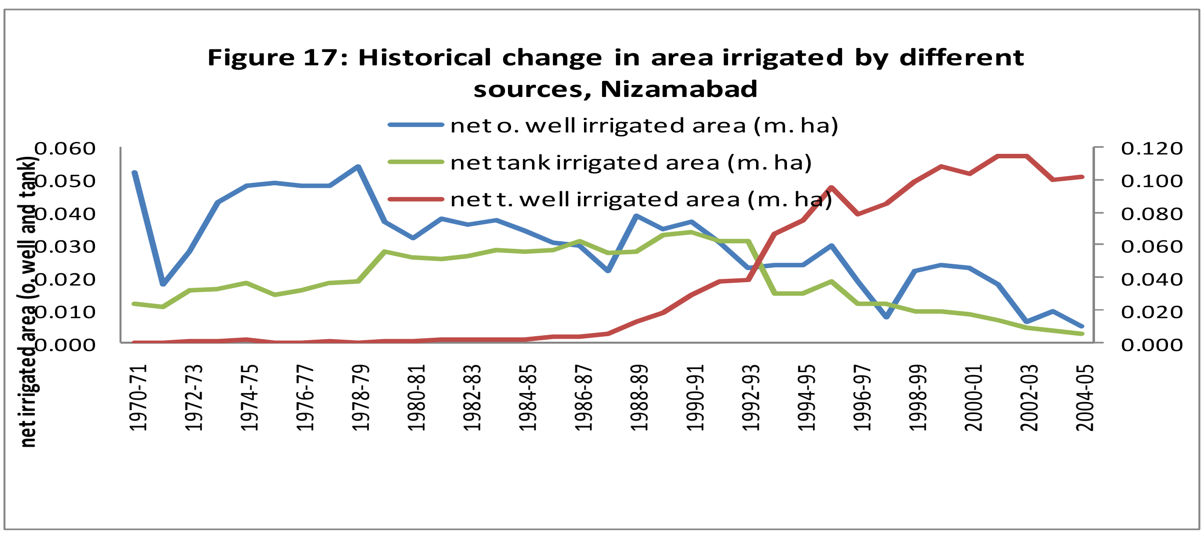
At the same time, increase in tube/bore well irrigation (from 0.98 m. ha in 1990-91 to 1.27 m. ha in 2004-05 by around 0.99 m. ha), which is also accompanied by reduction in open well irrigation, indicates the dewatering of shallow aquifers, and the pumping of water from the deeper strata. This not only means the chances for base flow contributing to streams flows into tanks are almost absent, but the possibility of tanks losing their storage into the dewatered aquifers would also be very high. Again under such geo-hydrological environments of deep dewatered zones, the response of shallow and deep aquifers to incident rainfall would be slower as compared to a situation where the shallow aquifer is saturated owing to the time taken for water to move from the top soil to the water table and the amount of water lost while percolating. Here, unlike in the earlier case, good rainfall may not result in proportional improvement in groundwater recharge and base flows, while tank inflows and tank irrigated area could increase due to increase in runoff. Therefore, rainfall will have a lesser influence on groundwater-tank interactions. This increase the negative effect of tube well/bore well irrigation on tank performance.

While intensive well irrigation explains the decline in tank irrigation to the extent of 48-63 per cent, clearly there are other factors which cause decline in tank irrigated area. We have hypothesized that change in land use would be another important factor, which cause reduction in tank inflows and tank-irrigated area. However, we can test this hypothesis only using primary data collected from the field, as the secondary data on land use are not available for individual tank catchments, but also mandals and blocks and districts.

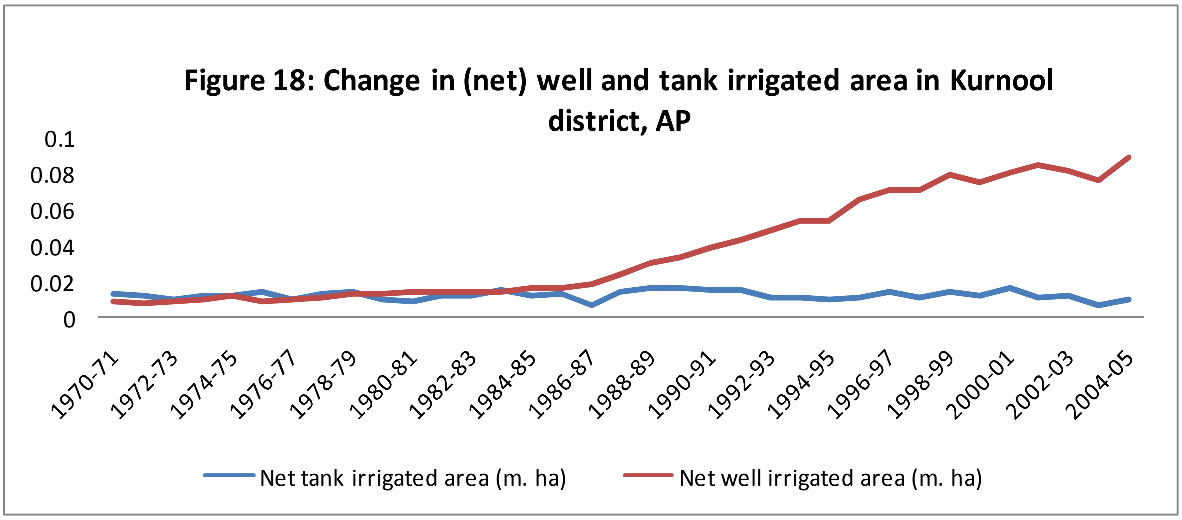


Differential Impacts of Well Irrigation on Tanks across Different Regions

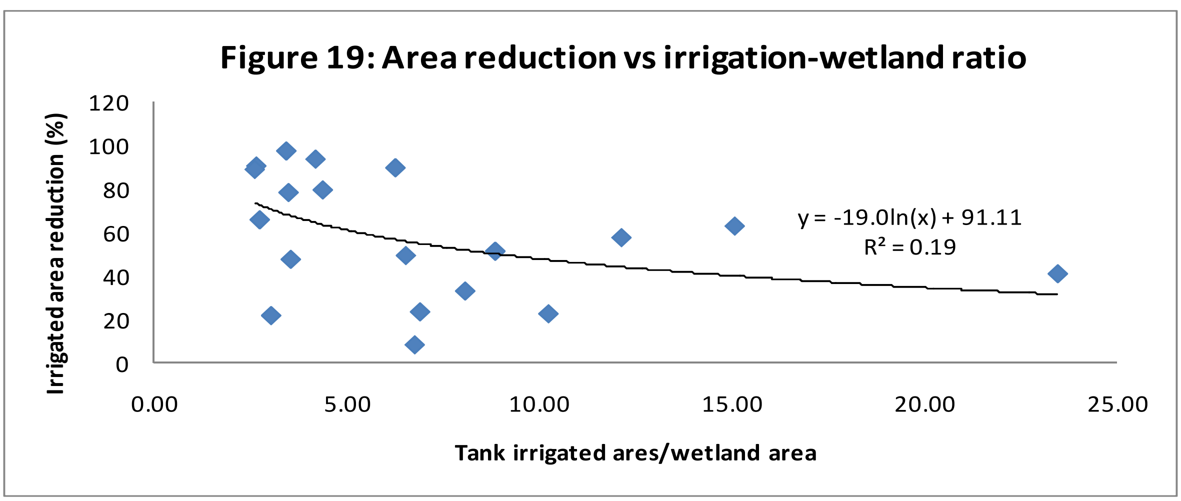
The foregoing analyses do not, however, suggest that the historical tank performance has been uniform across the board. In fact, analysis of tank irrigated area, well irrigated area and bore well irrigated area for different districts show distinctly different trends. For instance, in Nizamabad district, the decline in tank irrigated area was very sharp (Figure 17) an inverse linear relationship exists between tank irrigated area and well irrigated area , and the regression value is very high



(R^2=0.55 for both total well irrigated area and bore well irrigated area). For every one hectare increase in well irrigated area, the tank irrigated area declined by 0.25 ha. The relationship was quite week in the case of Vijayanagaram district. Interestingly, no relationship seems to exist between net tank-irrigated area and net well irrigated area (and also net bore well irrigated area) in the case of Kurnool district. In fact, the net area under tank irrigation did not show any consistent decline in the district (Figure 18), which has large tracts of forest land and many tanks, which have forested catchments.



Further analysis was carried out to examine whether any relationship exists between tank characteristics, defined by the ratio of the area irrigated by the tank and its wetland area, and the degree of reduction in irrigated area over time, which these tanks have undergone. The analysis was carried out using district as the unit. The percentage reduction in irrigated area was estimated for each district by taking the ratio of the reduction in area during 1970-71 to 2004-05 and dividing it by the area irrigated in 1970-71. Here, we assume that the area irrigated by the tank in 1970-71 reflect the best irrigation performance for the tanks in all the districts. Our analysis shows an inverse (logarithmic) relationship between the "irrigation-wetland area ratio" and the reduction in area which irrigation from the tank has undergone, defined in percentage terms (Figure 19). Greater the



value of the wetland-irrigation ratio, lower the reduction in area irrigated over time. Frequency analysis showed that tanks with wetland-irrigation ratio in the range of 2.0-5.0 experienced an average reduction in irrigated area of 73.5 per cent. Against this, those tanks having wetland-irrigation ratio exceeding 5.0 (between 6.26 and 23.47) experienced an average reduction in the irrigated area of only 48.70 per cent. Many districts in this category showed less than 25 per cent reduction in irrigated area. These analyses indicate that the tanks with low irrigation-wetland ratio are likely to deteriorate much faster than those with high irrigation-wetland ratio.

Impact of Catchment Land Use on Tank Performance: Analysis of Field Data

The impact of changes in land use in the catchment on the performance of tanks was analyzed by comparing temporal changes in total area under different crops and tank-irrigated area under different crops in different seasons in the command area against the temporal changes in types and density of groundwater abstraction structures and cropping in the catchment. The impact of land-use changes on tank performance was also analyzed by comparing the performance of two tanks in terms of percentage area under irrigation and irrigated area ratio at a given point of time against the characteristics of land use in the catchment of the tanks such as well density and area under cropping at that point of time.

The analysis was done for both tank level data and individual farmer level data. The tank level data included: a] area under different crops in different seasons in the command area and catchment area; b] area of different crops irrigated by tank water in different seasons in the command area; and, c] density of wells in the command area and catchment area.

The summary of analysis for the tank-level data is provided in Table 6. It covers the tanks which are performing well and tanks which are not so well performing from all the three districts. Two types of comparison in tank performance were possible. 1. The difference in temporal performance of tanks located in different districts. 2. Difference in historic performance of tanks from the same location (district). This is compared against the physical and socio-economic features of the tanks under study to understand the reasons for differential performance.

Table 6 provides the data on performance of the six tanks in terms of gross cropped area, gross irrigated area, irrigated area as a fraction of the cropped area, and irrigated area ratio for the command area, against the well density in command, well density in catchment and gross cropped area in the catchment. The main highlights are as follows.

Tanks in Kurnool are the best tanks in terms of the overall condition as it had sufficient storage even in the beginning of summer season. The catchment area of the tank is covered by reserve forests and as such has no cultivation or no wells. Though the irrigated area ratio (ratio of gross irrigated area against the command area) is small for the first tank (ranging from 0.53 in 1980 to 0.44 at present), a large amount of water from the tank is diverted for domestic water supplies. The survey showed that in addition to irrigation, the 300 families from the village also use tank water for livestock drinking. Second: the command area farmers of the first tank (relatively better condition) grow water intensive crops such as chilly along with paddy and jowar, whereas farmers in other district tanks growth low water consuming short duration pulses such as green gram and black gram, which largely uses residual soil moisture from the harvested paddy fields. Further, unlike in the case of both the tanks in Nizamabad and one of the tanks Vizianagaram, there are fewer wells in the command of the tanks surveyed in Kurnool.

As Table 7 shows, all the 26 farmers surveyed in the command were found to be using only tank water in Parumanchala tank. In the case of Padmaraja tank, only two of the 33 farmers surveyed were using well water. Hence, it can be very well assumed that in the case of Kurnool tanks, a remarkable share of the irrigation in the command is from tank water. In the case of Nizamabad, the well density in the command area of the degraded Jukkul tank has been increasing over time, and is very high now. Twenty two out of the 49 farmers surveyed from the tank command reported using well (bore well or open well) in conjunction with tank water while 12 of them use only well water. Hence, most of the irrigation reported in the command area must be from wells only. Therefore, though the irrigated area ratio for the tank command has been increasing, using that alone for comparing tank performance will be highly misleading. Interestingly, though Nalla tank is highly degraded, in the absence of wells, the farmers in the command only depend on tank water. Hence, the bad condition of the tank is reflected in the irrigated area, which has reduced over time.

Comparison between two tanks in the same location brings out the effect of catchment land use changes in a better way. In the case of Gundla tank in Nizamabad and Pedda tank in Vizianagaram, which were perceived as in good condition by the local people, the irrigated are ratio has increased over time. For instance in the case of Gundla tank, it increased from 0.99 in 1970 to 1.66 at present, whereas in the case of Pedda tank, it increased from 1.36 in 1970 to 1.45 at present. This is quite contrary to what was found in the districts in terms of historical performance of tanks. In both the districts, the tank irrigated area declined, while the decline was very drastic in the case of Nizamabad.

What makes these tanks distinct is the fact that there is no significant groundwater use in their catchments. While there are no wells in the catchment area of Gundla tank (tank of Nizamabad, which is in relatively better condition), there are very few wells in the catchment of Pedda tank (1 well per 20 ha of catchment). But, this increase in irrigated area cannot be attributed to the good condition of tanks alone. The current groundwater use in the command area is significant for winter and summer crops, through these are low water consuming crops. As seen during the field work in Vizianagaram, almost all farmers in the command area of Pedda tank have bore wells with electricity connections. Wells are the main source of water for irrigation of winter crops (maize) and summer crops. Even during the month of summer, a significant portion of the command area is under sesame, which is a short duration crop.

Contrary to these, in the case of Jukkul tank (degraded tank of Nizamabad), there are around 37 wells per 20 ha of the catchment area, as on today, which actually experienced an increase from around 13 wells per 20 ha in 1970 to 20 wells per 20 ha in 1990. Further, the area under cultivation in the catchment as on toady is 90 per cent, and it increased dramatically from 38.45 ha to 182.1 ha over a period of 40 years.

Table 6: Tank Performance Vs Tank Characteristics

Name of District	Tank No	Good/ Degraded	Name of the Tank	Command Area (ha)	Gross cropped area in the command (Ha)					Gross irrigated area in the command (ha)				
					1970	1980	1990	2000	Current	1970	1980	1990	2000	Current
Kurnool (A)	1	Good	Parumanchala	607.0		324.0	301.7	313.9	269.3		324.0	301.7	313.9	269.3
	2	Degraded	Padmaraja Tank	344.3			368.6	405.0	328.1			368.6	405.0	328.1
Nizamabad (B)	1	Good	Gundla Tank	122.31	121.41	141.75	141.75	170.10	202.50	121.41	141.75	141.75	170.10	202.50
	2	Degraded	Jukkul Tank	63.99	64.80	70.47	70.47	70.88	95.18	64.80	70.47	70.47	70.88	95.18
Vizianagaram (C)	1	Good	Pedda Tank	303.51	526.50	567.00	567.00	526.50	546.75	413.10	405.00	425.25	425.25	441.45
	2	Degraded	Nalla Tank	127.48	255.15	255.15	255.15	255.15	145.80	255.15	255.15	255.15	255.15	137.70

Table 6: Contd.

Tank Code	Percentage area irrigated					Irrigated area ratio for the year					Density of Wells in the Command Area					Density of Wells in the Catchment area				
	1970	1980	1990	2000	Current	1970	1980	1990	2000	Current	1970	1980	1990	2000	Current	1970	1980	1990	2000	Current
A1		1.0	1.0	1.0	1.0		0.53	0.50	0.52	0.44		0.008	0.008	0.008	0.008		0.04	0.04	0.09	0.09
A2			1.0	1.0	1.0			1.07	1.18	0.95			0.049	0.049	0.049	There are no wells in the catchment area				
B1	1.00	1.00	1.00	1.00	1.00	0.99	1.16	1.16	1.39	1.66	2.45	2.45	2.58	2.62	2.70	There are no wells in the catchment area				
B2	1.00	1.00	1.00	1.00	1.00	1.01	1.10	1.10	1.11	1.49		1.56	2.11	2.19	2.31	0.64	0.84	1.01	1.63	1.88
C1	0.78	0.71	0.75	0.81	0.81	1.36	1.36	1.40	1.40	1.45	0.21	0.21	0.20	0.16	0.20	0.124	0.124	0.082	0.049	
C2	1.00	1.00	1.00	1.00	0.94	2.0	2.0	2.0	2.0	1.1	There are no wells in the command area					There are no wells in the catchment area				

Table 6: Contd.

Tank Code	Gross cropped area in the Catchment					Catchment Area (ha)	Percentage area under cropping in the catchment					Major Tank Uses			
	1970	1980	1990	2000	Current		1970	1980	1990	2000	Current	Irrigation	Domestic Water Supply	Fisheries	Livestock
A1	There is no crop cultivation in the catchment					137.7						300	300	8	300
A2	There is no crop cultivation in the catchment					176.58						250	300	10	300
B1			40.47	80.94	202.34	243.00	0.00	0.00	0.17	0.33	0.83	300		100	1000
B2	38.45	38.45	44.52	40.47	182.11	202.50	0.19	0.19	0.22	0.20	0.90	150		30	300
C1	141.64	121.41	161.87	162.00	NA	121.50	1.17	1.00	1.33	1.33		1000		100	
C2	No data available				188.18	510.00	0.00	0.00	0.00	0.00	0.37	200		50	

Though there are no wells in the catchment of Nalla tank (degraded tank of Vizianagaram) in Vizianagaram district, rain-fed cultivation in the catchment has drastically increased over time--with the area increasing to 188 ha at present, covering 37 per cent of the catchment area. Probably due to this, the irrigated area ratio for the tank declined drastically from 2.0 to 1.1 during the period from 2000 to 2011. This means that the actual performance of tanks in terms of area served by it is much lower than the reported (irrigated) area in the tank command and in reality, might have declined.

Table 7: Percentage of Sample Farmers Using Different Sources of Irrigation in the Tank Commands

Name of Tank	No. of Farmers using different sources of irrigation in the command of					
	Nizamabad		Kurnool		Vizianagaram	
	Gundla tank	Jukkul Tank	Parumanchala Tank	Padmaraja Tank	Pedda Tank	Nalla Tank
Tank	29	12	26	28	20	20
Open Well		6		2	1	
Tank & Open Well		8			2	
Bore Well	5	3		1	3	
Tank and Bore Well	7	3			1	
Rain-fed		4		2	1	
Tank and Rain	1	11				
Open Well & Bore Well		1				
Open Well & Rain		1				
Total	42	49	26	33	28	20
Percentage Farmers Using Different Sources for Irrigation						
Tank	69.0	24.5	100.0	84.8	71.4	100.0
Open Well		12.2		6.1	3.6	
Tank & Open Well		16.3			7.1	
Bore Well	11.9	6.1		3.0	10.7	
Tank and Bore Well	16.7	6.1			3.6	
Rain-fed		8.2		6.1	3.6	
Tank and Rain	2.4	22.4				
Open Well and Bore Well		2.0				
Open Well & Rain		2.0				

Source: Authors' own analysis using primary data from tank water users

Agricultural Activities in the Command and Catchment of Tanks

In this section, we would analyze the changes in crop production in both the commands and catchments of the tanks. This is based on primary data collected from 25 farmers located in the command and catchments from each tank location, with a total of roughly 150 farmers from the six tanks selected for investigation. While the changes in cropping pattern and cropped area in the catchment is likely to influence the tank hydrology, the changes occurring in the cropping pattern and cropped area in the command area is a reflection of the changes in tank hydrology, and other farming related externalities which include the change in access to water from underground and other sources. As discussed in the first section, the scenario vis-à-vis access to groundwater had dramatically changed in Andhra Pradesh after the 80s with the advent of energized pump sets for extracting water from open wells, and bore wells that are able to tap water from deeper strata. If market conditions remain the same, reduced inflows into the tanks can force farmers to reduce the area under water intensive crops like paddy and sugarcane and shift to low water consuming crops like pulses. But, improved access well water, through energized pump sets and drilling technologies can enable farmers to intensify their cropping and go for irrigated crops during winter and summer seasons. The results of the analysis are presented district-wise and tank wise below.

Kurnool District

Tank 1: Parumanchala Tank, Parumanchala Village, Nadikotkur Mandal, Kurnool District

We have discussed the cropping pattern in the tank command for each case study tank in the previous section. But, that was based on data obtained from the tank users' association and the village leaders. As a result, it only captured the major crops grown in the command.

Table 8A shows the cropped area and cropping pattern of Parumanchala tank command for the period from 1970-2011 (current). The analysis shows that there has been a remarkable increase in the cropped area in the command during the past 40 years, with most of the expansion occurring the first decade i.e., 1970-80. During this period, the cropping intensity also increased substantially, with crops being cultivated during winter and summer, as against only during kharif prior to 1980. Thereafter, it had hovered around 155-165 ha. Even during 2000-11, the change is gross cropped area was negligible. While the area under kharif paddy did not show any major change during 1970-2000, the percentage area under kharif paddy drastically declined (from 69 per cent in 1970 to 4.8 per cent in 2011), as new crops were introduced in the command. These new crops include chilly, groundnut, tobacco, summer jowar, cotton and pulses. Chilly occupies nearly 45 per cent of the cropped area of the sample farmers, which is only second to jowar, which is the major kharif crop in the tank command today.

Table 8A: Gross Cropped and Irrigated Area (Acre) of Sample Farmers in Parumanchala Tank Command

Season	Crop	Area under the Crop in				
		1970	1980	1990	2000	Last Normal Year
Khariff	Paddy	30.2	30.2	30.2	30.2	8.0
	Maize			5.0		7.5
	Jowar	5.0	21.5	23.0	29.5	57.7
	Cotton	8.5	2.0	2.0	2.0	2.0
	Chilli		46.3	35.3	63.7	45.3
	Groundnut		7.0	7.0	7.0	12.0

	Tobacco		15.0	15.0	15.0	15.1
	Sunflower		7.5	17.5	5.0	5.0
	Pigeon Pea		10.0	10.0	10.1	15.1
	Black Gram			6.0		
Rabi	Black Gram		2.0	2.0	2.0	
Summer	Jowar		1.5			
	Tobacco		15.0			
	Chilli		15.0			
	Pigeon Pea		10.0			
	Total	43.7	182.9	152.9	164.5	167.7
Percentage Area of Crops in Parumanchala Tank Command						
Khariff	Paddy	69.1	16.5	19.7	18.4	4.8
	Maize			3.3		4.5
	Jowar	11.4	11.8	15.0	17.9	34.4
	Cotton	19.4	1.1	1.3	1.2	1.2
	Chilli		25.3	23.0	38.7	27.0
	Groundnut		3.8	4.6	4.3	7.2
	Tobacco		8.2	9.8	9.1	9.0
	Sunflower		4.1	11.4	3.0	3.0
	Pigeon Pea		5.5	6.5	6.1	9.0
	Black Gram			3.9		
Rabi	Black Gram		1.1	1.3	1.2	
Summer	Jowar		0.8			
	Tobacco		8.2			
	Chilli		8.2			
	Pigeon Pea		5.5			

*Note: The gross cropped and irrigated areas in Parumanchala Tank Command are one and the same.

The corresponding figures for the tank catchment are shown in Table 8B. The data shows that cropping is practiced only during kharif season, and ground nut and red gram being the major crops. These crops require much less irrigation water as compared to paddy. Though these are also reported to be irrigated, the availability of rains means that they require very little irrigation that too during the dry spell.

Table 8B: Gross Cropped and Irrigated Area (Acre) of Sample Farmers in Parumanchala Tank Catchment Area

Name of Season	Name of Crop	1980		1990		2000		LNY	
		Cultivated	Irrigated	Cultivated	Irrigated	Cultivated	Irrigated	Cultivated	Irrigated
Kharif	Groundnut	24	24			24	24		

	Red gram			24	24			14	14
	Tobacco							10	10

Source: authors' own analysis based on primary data

Tank 2: Padmaraja Tank of Indireswaram Village, Atmakur Mandal

Table 9 shows the cropped area, irrigated area and cropping pattern in the command area of Padmaraja tank, which is considered to be a well performing tank in the area for the period from 1980-2011. Since all the crops are irrigated in almost all situations, as one can see, the cropped area figures and irrigated area figures are more or less the same, except in 1990. As one can see, there has been no significant change in the cropped area in the tank command since 1980, except a 15 % increase during 1990-2000 as compared to the base year of 1980. Thereafter, the area under cropping and irrigation reduced slightly. The tank command also did not witness much change in the cropping pattern also. The area under paddy hovered around 69-85 per cent during the past 3 years. Unlike in the case of Parumanchala tank, where the percentage area under paddy reduced drastically after 1970, in this case, it went up slightly during 2000-11. Nevertheless, no major cropping was reported during the winter season, while at least four crops viz., cotton, sunflower, chilly, and jowar, were grown by farmers during the season during 1980-2000.

As regards tank catchment, no crops were grown there, as it is under reserve forest.

Table 9: Gross Cropped and Irrigated Area (Acre) of Sample Farmers in the Indireswaram Tank Command

Name of Season	Name of Crop	1980		1990		2000		Last Normal Year	
		Cropped	Irrigated	Cropped	Irrigated	Cropped	Irrigated	Cropped	Irrigated
Khariff	Paddy	119.8	119.8	92	92	145.3	145.3	135.8	135.8
	Cotton	3	3	6	6				
	Sunflower	22.5	22.5	9.3	3	11	11	4	4
	Maize	2	2	2	2	2	2		
	Jowar			22	22				
	Jute					3	3	3	3
	Gooseberry							17	17
Rabi	Cotton	2	2	2	2	2	2		
	Sunflower	3.5	3.5	3.5	3.5				
	Chilli	1	1	1	1	21.5	21.5		
	Jowar	2	2	2	2	2	2		
	Watermelon					1	1	1	1
	Total	155.8	155.8	139.8	133.5	187.8	187.8	160.8	160.8
Percentage Area of Crops Cultivated and Irrigated in the Indireswaram Tank Command									
Khariff	Paddy	76.9	76.9	65.8	68.9	77.4	77.4	84.5	84.5
	Cotton	1.9	1.9	4.3	4.5				
	Sunflower	14.4	14.4	6.7	2.2	5.9	5.9	2.5	2.5
	Maize	1.3	1.3	1.4	1.5	1.1	1.1		

	Jowar			15.7	16.5				
	Jute					1.6	1.6	1.9	1.9
	Gooseberry							10.6	10.6
Rabi	Cotton	1.3	1.3	1.4	1.5	1.1	1.1		
	Sunflower	2.2	2.2	2.5	2.6				
	Chilly	0.6	0.6	0.7	0.7	11.4	11.4		
	Jowar	1.3	1.3	1.4	1.5	1.1	1.1		
	Watermelon					0.5	0.5	0.6	0.6

Source: authors' own analysis using primary data

Nizamabad District

Tank 1: Jukkul Tank, Bhavanipet Village, Machareddy Mandal

The area under different crops grown in different seasons in Jukkul tank of Nizamabad district (a degraded tank) at different time intervals (1970, 1980, 1990 and 2000) and typical rainfall years (i.e., last normal year, last wet year and last dry year) by the sample farmers, and the corresponding cropping pattern are given in Table 10A. A quick review of the data shows that there has been a significant reduction in the gross cropped area since 1970--with the gross cropped area declining from nearly 60 acres in 1970 to around 36 acres in the last normal rainfall year.

As regards the cropping pattern, no pattern seems to be emerging, except that during dry years, farmers reduce the area under both kharif and winter paddy. Another important observation is that sugarcane was introduced as a major crop during 1980s, but had almost disappeared by 2000. This could be attributed to the introduction of energized wells in the area, and increase in command area farmers' access to well water for irrigation. Currently, the farmers in the command do not grow sugarcane. Overall, reduction in cropped area is a strong indication of water shortage faced by tank irrigators.

Table 10A: Gross Cropped Area under Different crops (Acre) of Sample Farmers in Jukkul Tank Command Area

Season	Name of Crop	Area under the Crop in					
		1970	1980	1990	2000	Last Normal Year	Last Drought Year
Khariff	Paddy	30.00	16.70	4.70	15.70	22.80	3.20
	Maize		5.15	1.60	13.75	1.00	19.10
	Sugarcane		12.00	23.45	1.75		
	Jowar						
Rabi	Paddy	29.45	10.05		12.20	11.15	1.00
	Maize		1.20		3.30	1.15	
	Sugarcane		0.15	0.60			
	Mustard						1.00

	Vegetable						
	Total	59.45	45.25	30.35	46.70	36.10	24.30
Khariff	Paddy	50.46	36.91	15.49	33.62	63.16	13.17
	Maize		11.38	5.27	29.44	2.77	78.60
	Sugarcane		26.52	77.27	3.75		
	Jowar						
Rabi	Paddy	49.54	22.21		26.12	30.89	4.12
	Maize		2.65		7.07	3.19	
	Sugarcane		0.33	1.98			
	Mustard						4.12
	Vegetable						

Source: authors' own estimates based on primary data

Since Jukkul tank is a degrade tank, it is important to examine the changes in farming systems in the catchment area. The data on total cropped area in different seasons and cropping pattern of the sample farmers in the catchment of the tank area are presented in Table 10B. The data shows that the area under cropping has increased in the command area, from 11.7 acre in 1970 to 21.20 acre in the last normal year (2011). An interesting observation is that sugarcane was introduced as a major crop as the data for 1990 indicate, but farmers did not continue this crop. Paddy continues to the dominant crop in the catchment, occupying around 80 per cent of the total cropped area, though in 2000 maize was the major crop occupying around 75 per cent of the gross cropped area.

Table 10B: Area under different Crops (Acre) of Sample Farmers in Jukkul Tank Catchment Area over the Years

Season	Name of Crop	Area under the crop in					
		1970	1980	1990	2000	Last Normal Year	Last Drought Year
	Paddy	5.20	7.20	0.20	2.00	8.20	
	Maize	1.50	5.00	1.50	9.80	5.00	9.30
	Sugarcane			10.00			
Khariff	Jowar						
	Paddy	5.00	6.20	0.20	1.00	7.00	
	Maize				0.20		4.00
	Sugarcane						
	Jowar		1.00			1.00	
Rabi							
	Total	11.7	19.40	11.90	13.00	21.20	13.30
Khariff	Paddy	44.4	37.11	1.68	15.38	38.68	
	Maize	12.8	25.77	12.61	75.38	23.58	69.92

	Sugarcane			84.03			
	Jowar						
Rabi	Paddy	42.7	31.96	1.68	7.69	33.02	
	Maize				1.54		30.08
	Sugarcane						
	Jowar		5.15			4.72	

Source: authors' own analysis using primary data

As regards the irrigation in the command, there has been an overall reduction in the area irrigated by tank—from 57 acres in 1970 to 34 acres last year, though maximum shrinkage in irrigated cropped area was reported for 1990 (by nearly 2/3d) (Table 11A). Thereafter, the irrigated area improved to become 45 acres in 2000 and then declined. In line with data on cropping pattern, maximum area under irrigated sugarcane was reported in 1990 (around 28 acres), occupying around 75 per cent of the total irrigated area in the command. A useful observation vis-à-vis irrigated cropping pattern is of maize becoming a dominant crop during drought years. During the last drought, it was reported to have occupied around 86 per cent of the total area under irrigation.

Table 11A: Gross Irrigated Area under Different Crops (Acre) of Sample Farmers in the Jukkul Tank Command

Season	Name of Crop	Area under the crop in					
		1970	1980	1990	2000	Last Normal Year	Last Drought Year
Khariff	Paddy	28.5	15.55	4.7	15.7	21.65	2.2
	Maize		5.15	1.6	13.75	1	18.95
	Sugarcane		12	22.3	1.75		
	Jowar						
Rabi	Paddy	28.45	9.05		12.2	10.15	
	Maize		1.2		2.3	1.15	
	Sugarcane			0.6			
	Mustard						1
	Vegetable						
	Total	56.95	42.95	29.2	45.7	33.95	22.15
Khariff	Paddy	50.04	36.20	16.10	34.35	63.77	9.93
	Maize		11.99	5.48	30.09	2.95	85.55
	Sugarcane		27.94	76.37	3.83		
	Jowar						
Rabi	Paddy	49.96	21.07		26.70	29.90	
	Maize		2.79		5.03	3.39	
	Sugarcane			2.05			
	Mustard						4.51

	Vegetable						

Source: authors' own analysis based on primary data

As regards the catchment land use (Table 11B), the irrigated area is more or less the same as that of cropped area, meaning all the crops cultivated in the catchment are also irrigated.

Table 11B: Irrigated Area under different crops (Acre) of Sample Farmers in Jukkul Tank Catchment

Season	Name of Crop	Area under the Crop in					
		1970	1980	1990	2000	Last Normal Year	Last Drought Year
Khariff	Paddy	5.20	7.00	0.20	2.00	8.00	
	Maize	1.50	5.00	1.30	9.60	5.00	9.10
	Sugarcane			10.00			
Rabi	Paddy	5.00	6.00		1.00	7.00	
	Maize						4.00
	Sugarcane						
	Jowar		1.00			1.00	
	Total	11.70	19.00	11.50	12.60	21.00	13.10
Percentage area under different crops							
Khariff	Paddy	44.44	36.84	1.74	15.87	38.10	
	Maize	12.82	26.32	11.30	76.19	23.81	69.47
	Sugarcane			86.96			
Rabi	Paddy	42.74	31.58		7.94	33.33	
	Maize						30.53
	Jowar		5.26			4.76	

Source: authors' own analysis using primary data

Tank 2: Gundla Tank, Domakonda Village and Mandal

Gundla tank is a better performing tank when compared to Jukkul tank. The outcomes of the analysis of data on cropped area and irrigated area of different crops in the tank command are presented in Table 12. Since no difference in cropped area and irrigated area was seen, or in other words, since all the crops were irrigated, the outputs for cropping pattern and irrigation are presented in Table 11. In the case of Gundla tank, no notable and consistent reduction or increase in area reported by the farmers was seen over the years. What is more important is the fact that paddy remained as the most dominant crop in the command, raised during both kharif and winter season and occupying more than 80 per cent of the cropped area.

Table 12: Area under Different Crops (Acre) and Irrigation of Sample Farmers in Gundla Tank Command

Name of Season	Name of Crop	Area under the Crop in					
		1970	1980	1990	2000	Last Normal	Last Drought

						Year	Year
Khariff	Paddy	51.6	62.9	6.9	64.4	61.9	57.6
	Maize					5.0	9.0
Rabi	Paddy	48.2	62.9	57.0	41.5	45.9	26.0
	Maize			2.0	2.0	5.0	10.0
	Total	99.8	125.9	66.0	107.9	117.8	102.6
Khariff	Paddy	51.7	50.0	10.5	59.7	52.6	56.1
	Maize					4.2	8.8
Rabi	Paddy	48.3	50.0	86.4	38.5	38.9	25.4
	Maize			3.0	1.9	4.2	9.8

Source: authors' own analysis

Vizianagaram District

In the case of the two tanks selected from Vizianagaram district, no cultivation in the catchment was reported by farmers through the village survey showed some cultivation in the catchment area. As per the tank level data obtained from the village tank users' association, no data on cropping are available for the present situation in the case of Pedda tank, no data on historical cropping (1970-2000) are available for Nalla tank. Though a lot of discrepancy is observed vis-vis data on land use in the catchment, the fact remains that there are no wells in the catchment area, which is suggestive of low intensity of land use there in terms of agriculture. Hence the output tables are only for cropped area and irrigated area in the tank command.

Tank 1: Pedda Tank, Rellivalasa

In the case of Pedda tank, which is considered to be one in good condition, the area under cropping had consistently increased from 1970 to 2000 (Table 13). But, later on the total cropped area of sample farmers declined to around 108 acres in 2011, the last normal year. The increase in cropped was also accompanied by increase in area under paddy, winter groundnut and summer maize. As regards the cropping pattern, the percentage area under paddy, groundnut and maize did not fluctuate much over the years. The area under irrigation was also found to be same as that under cropping as all the crops were irrigated. Currently, farmers are found to be growing sesame during later summer, which lasts till the end of July.

Table 13: Gross Cropped Area (Acre) of Sample Farmers in Pedda Tank Command of Rellivalasa

Name of Season	Name of Crop	Area under the crop in					
		1970	1980	1990	2000	Last Normal Year	Last Drought Year
Khariff	Paddy	27.1	33.3	36.7	38.5	27.1	31.7
	Maize	28.1	32.6	36.8	38.5	27.1	31.7
Rabi	Paddy	2	2	2	2	2	1
	Maize	2	2	2	2	2	1

	Groundnut	26.4	31.2	34.2	36.3	25.5	29.6
	Green Gram					1	
Summer	Maize	27.7	32.5	35.2	37.5	23	26.4
	Total	113.3	133.6	146.9	154.8	107.7	121.4
Percentage area under different crops over the years							
Khariff	Paddy	23.9	24.9	25.0	24.9	25.2	26.1
	Maize	24.8	24.4	25.1	24.9	25.2	26.1
Rabi	Paddy	1.8	1.5	1.4	1.3	1.9	0.8
	Maize	1.8	1.5	1.4	1.3	1.9	0.8
	Groundnut	23.3	23.4	23.3	23.4	23.7	24.4
	Green Gram					0.9	
Summer	Maize	24.4	24.3	24.0	24.2	21.4	21.7

Source: authors' own analysis based on primary data

Tank 2: Nalla Tank of Pinavemali, Vizianagaram Mandal

In the case of Nalla tank, As Table 14 shows, the total cropped area of sample farmers surveyed in the command consistently decreased from 153.7 acres in 1970 to as low as 91 acres in 2000, and then increased to 165 acres in the last normal year (2011). But, a substantial portion of this increase in area came from pulses such as green gram and black gram, which are very low water consuming, short duration crops. The area under green gram and black gram went up by 52 acres. Though area under kharif paddy, which receives only supplementary irrigation, was very high during the last normal year (a rise of 38 acres from 2000 figures), there was reduction in area under winter maize, which is fully irrigated. The gross cropped area was, however, down to 116 acres in the last drought year. The percentage area under paddy did not change significantly during the forty year period from 1970-2011, though it was highest during 1990.

Table 14: Gross Cropped Area (Acre) of Sample Farmers in Nalla Tank of Pinavemali Command Area

Season	Name of Crop	Area under Different Crops over the Years					
		1970	1980	1990	2000	LNY	LDY
Khariff	Paddy	57.8	44.2	42.2	34	72.8	41.5
	Maize		3	1	8	3	
Rabi	Green Gram	46	34	18.4	16.9	51	40.5
	Black gram	39.9	31.3	22.9	14.2	32.4	28.4
	Maize	10	3	5	18	6	6
	Total	153.7	115.5	89.5	91.1	165.2	116.4
Khariff	Paddy	41.2	38.3	47.2	37.3	44.1	35.7
	Maize	0.0	2.6	1.1	8.8	1.8	0.0
Rabi	Green gram	29.9	29.4	20.6	18.6	30.9	34.8
	Black gram	26.0	27.1	25.6	15.6	19.6	24.4
	Maize	6.5	2.6	5.6	19.8	3.6	5.2

Source: authors' own analysis using primary data

The irrigated area in the Nalla tank command is a little lower than the cropped area, with a small portion paddy is left un-irrigated (Table 15). Paddy occupies nearly 45 per cent of the cropped area. Nevertheless, during drought year, the percentage area under

Table 15: Area Irrigated under Different Crops (Acre) of Sample Farmers in Nalla Tank of Pinavemali Command Area

Name of Season	Name of Crop	Area under the crop in					
		1970	1980	1990	2000	LNY	LDY
Khariff	Paddy	57	43.2	42	31.6	61.8	19.8
	Maize		3	1	8	3	
Rabi	Green gram	38.22	23.4	17	16.9	40.2	21
	Black gram	34	19.5	14.7	14	28	20
	Maize	9	3	5	18	6	0.5
	Total	138.22	92.1	79.7	88.5	139	61.3
Percentage Area under different crops in the Nalla Tank Command							
Khariff	Paddy	41.2	46.9	52.7	35.7	44.5	32.3
	Maize	0.0	3.3	1.3	9.0	2.2	0.0
Rabi	Green gram	27.7	25.4	21.3	19.1	28.9	34.3
	Black gram	24.6	21.2	18.4	15.8	20.1	32.6
	Maize	6.5	3.3	6.3	20.3	4.3	0.8

Performance of Tanks against their Physical and Socio-economic Attributes

We started off with the basic premise that gross irrigation as a ratio of the command area (irrigated area ratio) is an important indicator of tank performance, and then went on to analyze the effect of groundwater irrigation and crop cultivation in the catchment on tank performance. But, our analysis shows that this can often be misleading due to two reasons. *First*: the cropping pattern changes drastically from tank to tank, and often is a function of the tank hydrology itself. The farmers in the command area of tanks which receive sufficient inflows tend to grow highly water intensive crops such as chilly, sugarcane and sunflower, whereas those in the command area of tanks facing water shortage tend to grow low water consuming crops after the monsoon paddy.

From perennially water-rich tanks, water is also used for domestic water supplies in the neighbouring villages and small towns, apart from livestock drinking. Farmers grow crops such as pulses in the tank command after kharif paddy in view of severe water shortage. *Second*: the presence of wells in the tank command alters the scenario of irrigated area in the tank command. Even in instances where the tanks are not able to serve the command area farmers because of reduced inflows from the catchments, the wells in the command area meet the crop water requirement. But, under no circumstances, the presence of wells in the command influences the farmers not to use the tanks. Instead, it is the inability to get sufficient water from tanks for irrigating crops that motivates them to go for well irrigation. Therefore, high density of wells in the command area should be treated as a sign of low dependability of tank system as a source of water for irrigation and other uses in the command.

When the analysis looked at the variations in cropping pattern in the command area, the uses of tank water other than for irrigation (like domestic water supply to towns and villages and livestock drinking), and the effect of wells in the tank command on irrigation performance to do the comparative performance of tanks, the following becomes clear. The performance of those with high density of wells in the catchment area and high land use intensity are likely to decline drastically over time, whereas those without much interception of their catchments through faming and groundwater withdrawal sustain their performance, without any threat to the hydrological integrity. The best performing tanks will be those which have no cultivation in the catchment (which also implies that there are no wells), and the second best are those which have no wells in the catchment, but have rain-fed cultivation. As a result, tanks which have their upper catchments located in forests are the most ideal ones in terms of performance.

FINDINGS

A**n** extensive review of the past research initiatives on tanks show a heavy bias in the focus on sociological aspects. While several researchers have enquired into the causes for decline of tank irrigation in South India, the range of factors to which they have attributed the "decline", are largely social and institutional. The most dominant of them are the lack of incentive among the command area farmers[3], and collapse of traditional management institutions, including community management structures and institutions of overlords (*Zamindars*) which took care of their upkeep, increase in groundwater irrigation and the consequent reduction of interest among farmers in tanks, interception of supply channels, and lack of adequate attention paid to regular maintenance.

The arguments about collapse of traditional institutions as the cause of "tank decline" are based on a resounding view that even the external factors, which have potential influence on the tank performance, were within the control of these institutions. On the contrary, there are several physical and socio-economic changes taking place in and around the tank systems over time, which could have impacted on tank performance, and are not within the control of these institutions. They inadvertently ignore the fact that these institutions existed in a certain socio-political framework, which cannot be recreated. Again, such views are based on the assumption that simply cleaning supply channels, or clearing the catchments or repair of the tank embankments (tank bunds), and de-silting of the distribution network would yield results in terms of improved storage in tanks and expanded irrigation benefits. So far as the well irrigation argument goes, it assumes that wells were within the reach of all segments of peasant, small and big. This again is not true as only a tiny fraction of the small and marginal farmers own wells, and still have great stakes in tanks.

These factors at best became contextual variables for tank deterioration, and not explanatory variable as the causality has not been tested. Conversely, it is probably the decline in tank performance due to extraneous reasons had resulted in community's disinterest in their management, with the cost of maintaining them surpassing the actual benefits that can be accrued from their upkeep. We propose an alternative hypothesis that excessive groundwater draft characterized by groundwater irrigation in the tank catchment and commands, and land-use

[3] This is evident from the poor participation of the communities in tank management operations, and encroachment of tank bed and tank catchment by the villagers.

changes in the catchment in the form of intensive crop cultivation resulted in reduced tank inflows, causing decline in area irrigated by tanks. These hypotheses were tested using: a] secondary data available from government agencies at the district level on area irrigated by tanks and wells; and b] primary data collected from tank communities at the local level on changes in groundwater irrigation in catchments and commands, and changes in catchment land use.

Groundwater irrigation has been growing steadily in Andhra Pradesh since the early 70's till the end of the last century, as indicated by the figures of net total well irrigated area. This has been evident through increase in number of deep bore wells and energized pump sets for open wells and bore wells. As our analysis shows, the net well irrigated area began to "plateau" after 2000-01. Thereafter, as pointed out by Kumar *et al*. (2011), the increase in number of wells had not resulted in increase in gross well irrigated area either.

Analysis of the dynamics of interaction between groundwater and tanks at the level of the state and districts showed that increased groundwater draft adversely affected the performance of tanks, as indicated by the strong correlation between well and bore well irrigated area and net area irrigated by tanks at the state level for AP, and also for many districts of the states. Therefore, it could be safely argued that much of the expansion in well irrigated area happened at the cost of tank irrigation. Nevertheless, the effect of well irrigation on tank performance hasn't been uniform. While in many districts, the decline in tank performance in terms of "net area irrigated by tanks" in response to increase in "net well irrigated area" has been sharp, in some districts, there hasn't been much reduction in the net tank irrigated area, in spite of remarkable increase in well irrigated area.

In lieu of the adverse impact of well irrigation on tank performance, it could be stated that though the net increase in well irrigated area in the state has been a remarkable 1.4 m. ha (net), the overall contribution of wells to expansion of irrigation in the state will be much less, if one takes into account the fact that the reduction in net tank irrigated area is around 0.60 m. ha, i.e., from 1.11 m. ha to 0.47 m. ha. But, the reduction in tank irrigated area cannot be fully attributed to groundwater over-extraction, and part of the reduction might have been caused by the change in land use in the tank catchments.

Analysis carried out to examine the relationship exists between tank characteristics, defined by the ratio of the area irrigated by the tank and its wetland area, and the degree of reduction in irrigated area over time showed an inverse (logarithmic) relationship between the "irrigation-wetland area ratio" and the reduction in area which irrigation from the tank has undergone, defined in percentage terms. Greater the value of the wetland-irrigation ratio, lower the reduction in area irrigated over time. Frequency analysis showed that tanks with wetland-irrigation ratio in the range of 2.0-5.0 experienced an average reduction in irrigated area of 73.5 per cent. Against this, those tanks having wetland-irrigation ratio exceeding 5.0 (between 6.26 and 23.47) experienced an average reduction in the irrigated area of only 48.7 per cent. Many districts in this category showed less than 25 per cent reduction in irrigated area. These analyses indicate that the tanks with low irrigation-wetland ratio are likely to deteriorate much faster than those with high irrigation-wetland ratio.

As regards the impact of catchment land use on tanks, different types of changes are occurring over time, which have significant impact on runoff affecting the hydrology and performance of tanks. While some of them are positive, some of them are negative. The first type of change is in the area under cultivation in the catchment. The catchments of tanks are generally public land with government forests, pasture land and revenue wasteland. Barring the reserve forests (like in Kurnool), these catchment are increasingly being encroached-upon by individual villagers for cultivation as found in the case of Jukkul and Gundla tank in Nizamabad. One factor which triggered intensive land use in the catchment is the access to well irrigation. In the case of Jukkul tank, the density of wells in both command and catchment has been going up over the years and is currently very high. With water available from wells for supplementary irrigation, farmers are able to take up cultivation of kharif crops even in the driest regions of the country. Hence, intensive groundwater irrigation in the catchment had double impact on tank hydrology, first by affecting the groundwater outflows into streams and the second by affecting the runoff from the catchment entering the tank reservoir.

Cultivation alters the catchment hydrology by reducing the runoff generation potential of the incident rainfall and the impoundment of part of the generated runoff into the cultivated fields through the field and farm bunds. Often, afforestation activities are undertaken in the catchment by community organizations, which affect runoff generation. The trees such as eucalyptus which were preferred for plantation under afforestation programme were water-guzzlers. They can suck groundwater apart from taking runoff and soil moisture. Such changes are occurring everywhere in the rural landscape. But, there are two notable exceptions. 1. Places where the forests constitute the main catchment of tanks. 2. Areas where groundwater development is not feasible for agricultural intensification due to presence of hard rock geology, and outcrops of underlying geological strata. Thus, in areas which have experienced significant changes in land use in the form of expansion of cultivation in the catchment, it won't be economically prudent to invest in tank rehabilitation.

The second type of change in the catchment land use is caused by the use of clayey soils in the catchment and tank bed for brick making etc., with soil being excavated. With booming construction activity in the state, there is mounting demand for bricks. The pressure on catchment land and tank bed for such uses is more in case of tanks which are located in the vicinity of towns. Such activities can also change the runoff or storage potential of the tank catchment, depending on the place from where the soil is excavated. In such situations, the communities or the local Panchayats will not have much interest in reviving the tanks as the income earned from such activities is very large.

The third type of change is the interception of the drainage lines in the catchment. There are two different types of activities which cause this interception. 1. Construction of roads and buildings. This again is more relevant for tanks which are in the periphery of towns. This can divert the runoff water to different areas, thereby reducing the tank inflows. 2. The indiscriminate construction of water harvesting structures such as check dams in the name of watershed development. This is very rampant in Andhra Pradesh, like in many semi arid states of the country. The absence of any kind of regulations on water resources in the state had actually precipitated in serious concerns. One of the reasons for this unprecedented increase in water harvesting schemes is that the demand for water in agriculture has increased in the upper catchments of river basins with growing population pressure, and with depleting groundwater resources the communities and NGOs have moved on to small water harvesting systems. Here again, such actions will be noticeable in areas with poor groundwater potential (underlain by hard rock basalt or crystalline rocks), and not in groundwater rich (alluvial) areas. In such areas, which have experienced intensive water harvesting and watershed treatment work and where such inflow reduction is clearly visible, it won't be economically prudent to invest in large-scale tank rehabilitation.

The degradation of tanks occurring as a result of changes in tank hydrology also seems to affect the success of the rehabilitation programme. It was observed that in the case of Kurnool and

Nizamabad districts, more money was spent for rehabilitation works of those tanks which are actually not performing well as compared to the good ones. In spite of this, the condition of poorly performing tanks did not improve.

In the final analysis, it appears that it is groundwater intensive use in upper catchment or lower catchment which will have the most remarkable impact on hydrology and performance of tanks. This is because, pumping of water from wells while reducing the groundwater outflows into streams, also leads to intensive use of land in the catchment for cultivation, which further leads to reduction in runoff generation and in situ harvesting of a portion of that runoff for storage in soil profile.

Protocol for Tank Rehabilitation

- Prior to the selection of any tank for rehabilitation, the potential of its catchment to yield sufficient water as inflows into the reservoir needs to be ascertained. For this the catchment yield with 75% dependability could be considered. The estimate of catchment yield should be compared against the total water demand for competitive uses that exist for the tank under consideration like irrigation, domestic and livestock use and fisheries. Only those which offer sufficient physical feasibility should be taken up for rehabilitation. In other words, tanks which do not receive sufficient inflows to serve the full command area even one out of three years, need not be taken up for rehabilitation. Tanks which receive inflows to the full storage capacity or sufficient water to meet the demand of the design command area in three out of four years, should receive highest priority for rehabilitation. But this vital hydrological data on stream flows, which is an important input for hydrological planning of tanks, are not available for most tanks that either falls under the jurisdiction of Minor Irrigation department or the Panchayats.

- This makes it imperative to study the land use in the tank catchment and command thoroughly, before embarking on rehabilitation of the tank system. It is quite evident that for catchments which have undergone major changes in land use, new models for runoff estimation will have to be developed, instead of using old rainfall-runoff models developed on the basis of observed stream flows of the past, when land use and land cover were remarkably different. The outdated methods for runoff estimation like the "rational formula", which uses a constant runoff coefficient, can lead to under-estimation or over-estimation of dependable runoff.

- The most pragmatic approach for estimating dependable yield from tank catchment would be to estimate runoff for historical rainfall for the current land use in the catchment using US Soil Conservation Bureau's Curve Number method, and then estimate the runoff of certain dependability. Here again, using the average rainfall or dependable rainfall (75% dependability) will lead to erroneous results. Thereafter, for arriving at the net stream flows, the groundwater outflows into tank inflows or tank infiltration into underlying aquifers can be computed by incorporating the groundwater draft from catchments and command in water balance models. In many situations, it may be necessary to redesign the tank command on account of the changing land use in the catchment and tank hydrology, and the new cropping systems which farmers have introduced in the area.

- For estimation of water demand for irrigation, kharif paddy in the entire command, and a short duration winter crop in 1/4th of the command assumed reasonably. For this, the existing cropping pattern of the area and the most desirable cropping pattern from the point of view of agro climate should be used as the basis. Since the irrigation water demand for paddy would vary widely between a drought year and a wet year, the amount of irrigation (depth of irrigation) required during a normal year could be considered for demand estimation.

- In the case of cascade tanks, the upper catchment tanks should receive highest priority, if there are in need of repair or rehabilitation. This is because they are least likely to face problems of encroachment, change in land use in the catchment and intensive groundwater development in the catchments and command areas, by being located in forest catchments.

Quantitative Criteria for Choosing Tanks for Rehabilitation

5. It is quite evident from the foregoing analysis that choosing any tank for rehabilitation would involve certain costs, for micro level hydrological studies to estimate the water availability from the catchment and the demand for water in the tank command. Therefore, it is necessary to evolve simple and quantitative criteria for short-listing tanks for conducting detailed investigation, to finally decide on the nature of rehabilitation.

6. The analysis indicates that tanks which have relatively higher "irrigation-wetland area ratio should be given priority. The reason is that such tanks are likely to experience less deterioration as compared to those having low irrigated area-wetland area ratio. This is evident from the fact that tanks, which had low irrigation-wetland area ratio (from 2.0 to 5), showed high rate of degradation with the reduction in area irrigated touching almost 74 per cent. One of the hydrological explanations for this is that such tanks would have higher losses from percolation as a result of increased groundwater draft. In areas where fishery is a major economic activity preferred by the tank communities, then the minimum water required in the tank for fish production should be considered instead of water requirement for winter crop production, for assessing the suitability for rehabilitation work.

7. Tanks with low density of wells in the command area and catchment area and low intensity of land use in the catchment need to be given priority while choosing tanks for rehabilitation. While it is difficult to arrive at a quantitative criterion for selecting tanks for rehabilitation based on number and density of wells in the catchment, a well density of twenty and above for 20 ha of command area (or one well per ha of command) is a clear sign of diminishing importance of tanks for the farmers' livelihoods. On the other hand, a well density of 0.5 and above, i.e., one per two ha of land, is a clear indication of high intensity of land use in the catchment area, with multiple cropping. This can reduce the inflows into the tanks drastically by capturing the runoff in situ, and reducing the groundwater outflows into surface streams.

8. Large number of wells in the tank command may also indicate declining importance of tanks in the irrigated livelihoods of farmers in the command, though vice versa may not be true. The argument that farmers abandon tanks because of wells is not true. As seen in the case of Kurnool tanks, because of sufficient inflows into the tank reservoir, farmers still haven't started exploiting groundwater, though the area is extremely suitable for groundwater exploitation. On the contrary, owing to deteriorating condition of tanks, farmers are forced to go for well drilling in the command, wherever geo-hydrology permits. Nevertheless there can't be a standard norm on well density and catchment land use, for selecting or rejecting tanks for rehabilitation. The effect of well density and catchment land use intensity on tank inflows would also depend on the rainfall of the region and the physiographic features of the catchment. In high rainfall regions with steep slopes in the catchment, the norm could be relatively flexible, whereas in semi arid and arid regions with low to medium rainfall, the norm will have to be more stringent.

CONCLUSIONS AND RECOMMENDATIONS

The various tank rehabilitation programmes initiated by the state government of Andhra Pradesh under different schemes were primarily based on the assumption that the performance of tanks is declining across the areas, and the declining performance of these tanks is mainly due to the poor physical infrastructure because of the village community's lack of interest in managing them by carrying out regular operation and maintenance. Further it is assumed that they can be revived by undertaking physical rehabilitation of the engineering infrastructure, and some social engineering to organize the communities. Serious thought was not given to understand understanding the reasons for the declining interest of communities in managing the resource which had been the main stay of their livelihood for many centuries.

The work by several researchers seem to suggest that decline of tanks was due to events, starting with the takeover of community and Zamindari (Private) tanks by the state, collapse of the system for collection of water charges and lack of maintenance leading to deterioration of the physical condition of this irrigation infrastructure, and the subsequent declining of community interest. The factors thus responsible for decline of tanks were argued to be "institutional". However, these arguments suffer from weaknesses. For instance, if the argument that advent of groundwater irrigation had really led to the loss of farmer interest in tanks, is valid, then it tends to assume that groundwater irrigation is highly equitable and provides farmers from all segments access to and control over well irrigation. This is far from the truth, as only a small fraction of the small and marginal farmers in India even today own wells, and pump sets.

It is the small and marginal farmers, who do not own irrigation wells in the tank commands, who have high stakes in tank irrigation as their livelihood is mainly dependent on it. If this is the case, one cannot explain the poor condition of tanks in areas such as Kolar in Karnataka and Anantapur in AP, where the poor small and marginal farmers are often dependent on water purchase from well owners engaged in water trading, with standard reasons like "loss of community interest" in the management of tanks. It is also a notable fact that most of the beneficiaries of tank water for irrigation are small and marginal farmers.

The dominant theories on tank decline, which harp on collapse of traditional tank institutions as the cause of decline of tank irrigation, be it the institutions of overlords, or community management structures, are also suggestive of a resounding view that management of tank as a system is very much within the control of the farmers in the command areas or the institutions which manage them. They inadvertently ignore the fact that these institutions existed in a certain socio-political landscape, which is difficult or even impossible to recreate.

Such views are based on the assumption that simply cleaning supply channels, or clearing the catchments or repair of the tank embankments (tank bunds), and de-silting of the distribution network would yield results in improved storage in tanks and expanded irrigation benefits. In the process, little attention was paid to how the changes in catchment land use and groundwater draft in the catchments and commands could negatively influence the hydrological integrity of the tanks and their performance, which in turn can change the incentive structure for the farmers to manage them. This has led to large-scale initiatives by government as well as NGOs and donor community to support rehabilitation of all kinds of tanks with accent of engineering work and institution building, with poor results. We have therefore proposed an alternative hypothesis.

An alternative hypothesis is that population growth had a significant demand on irrigation water for crop production in these semi arid regions, which forced farmers to go for alternative sources of irrigation. Further, with a manifold increase in rural population and with the increase in number of farmers within the limited command of these tanks, the actual area which a single farmer could irrigate using tank water became too small for them to manage their farming enterprise. Well irrigation not only became affordable and in some cases cheaper, it also provided a superior form of irrigation.

The increase in pressure on private land also led to encroachment of commons, which formed the original catchments of tanks. Catchment cultivation resulted in a lot of the rainfall runoff being captured through *in situ* water harvesting for production of rain-fed crops, reducing the inflows into the tanks. Intensive well irrigation on the other hand led to reduced groundwater outflows into the upper catchment tanks. Whereas draw down in water table resulting from excessive withdrawal of groundwater could potentially lead to greater percolation of water from tanks into the shallow aquifers.

Thus the reduced irrigation potential of tanks on the one hand and the increasing number of tank water users in the command area essentially meant that the contribution tanks could make in the overall livelihood of individual command area farmers was too small in comparison to the transaction cost of initiating actions that would improve their performance. This significantly reduced the incentive among the members of the farming community for self-initiated management actions. We tested this hypothesis using primary data collected from the commands and catchments of six tanks located in three river basins of Andhra Pradesh, and macro level historical data on performance of tanks in the state.

Our analysis using secondary data on district-wise well irrigated area pointed that groundwater intensive use affects performance of tanks assessed in terms of the area irrigated by them. In Andhra Pradesh, the impact of bore well irrigation on tank performance appears to be higher than that of open wells. Though there are factors other than area irrigated, which need to be considered for assessing the performance of tanks, for a temporal study this could form a useful indicator of tank performance. But, the adverse impact of intensive well irrigation on tank performance in terms of reduction in tank irrigated area hasn't been uniform across districts.

Analysis based on primary data collected from the tank commands and catchments on the physical characteristics and socio-economic aspects show that land use and density of wells in the catchment are major determinants of tank performance. While low density of wells and low land use intensity in the catchment provide favourable conditions for sustaining the hydrological integrity of tanks and therefore their performance, high density of wells in either catchments or commands and high degree of crop cultivation in the catchment are clearly indicative of deteriorated condition of tanks, though vice versa may not be always true. Increasing intensity of wells and expansion in area under cultivation in the catchment reduces the irrigation performance of tanks, measured in terms of irrigated area ratio.

The protocol for tank rehabilitation should include estimation of the actual catchment yield potential of the tank catchment. This will require thorough understanding of the catchment land-use, to be incorporated in the runoff estimation models which use historical rainfall data for several years to estimate the dependable runoff from catchment. Groundwater draft from the catchment and command can then be simulated in a water balance model to compute the groundwater outflows into tanks or tank infiltration into aquifer for arriving at net catchment. This should be followed by realistic estimation of the water demand in the command, which takes into account the existing cropping pattern, and the variations in crop water demands in lieu of the rainfall variability--from dry year to wet year. In the case of cascade tanks, the upper catchment tanks should receive highest priority in rehabilitation programmes. This is because they are least likely to face problems of encroachment, change in land use in the catchment and intensive groundwater development in the catchments and command areas, they being located in forest catchments.

Since such micro level studies for examining the feasibility of tank rehabilitation involve costs, some simple and quantitative criteria were identified to shortlist tanks for detailed studies which would help in investment decision making on rehabilitation. To begin with, tanks which have relatively higher "irrigation-wetland area ratio" (above 5.0) should be given priority for rehabilitation. The reason is that such tanks are likely to experience less deterioration as compared to those having low irrigated area-wetland area ratio. This is evident from the fact that tanks, which had low irrigation-wetland area ratio (2.0 to 5), showed high rate of degradation with the reduction in area irrigated touching almost 74 per cent. The other useful criteria are density of wells in the catchments and command, and land use intensity in the catchment. Higher the values of these variables lower the feasibility of doing successful rehabilitation to improve tank performance.

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