CHAPTER 8: SUMMARY, CONCLUSION AND POLICY IMPLICATIONS

The importance of groundwater irrigation in the economic development of India has been well recognised by various empirical studies. Groundwater irrigation was instrumental in enhancing food security and mitigating poverty in developing countries. Groundwater irrigation provided opportunities to increase net irrigated area leading to increase in crop intensity and productivity (FAO 2003). Nevertheless, groundwater irrigation also contributed to the depletion of groundwater aquifers. The implications of groundwater depletion are manifold. Global research indicates that the severity of groundwater depletion reached a critical stage in many arid and semi-arid regions and posed severe threats to livelihood and the economic development of these regions (Shah 1988, 1993; Dhawan 1993, 1995; Llamas and Santos 2003; Moench 1995; Janakarajan 1993; Chandrakanth and Arun 1996; Shivakumarasway and Chandrakanth 1997; Nagaraj 1994; Vaidyanathan 1996; Nagaraj et al 1994). Poor access to groundwater adversely affects the livelihood of the poor in terms of economic viability. It can also lead to decline in use efficiency.

The expansion of groundwater irrigation was the result of several factors. The expansion of the rural electrification programme, liberal loan assistance for setting up, deepening and energisation of wells, and subsidised supply of energy together fuelled groundwater irrigation. Improvements in well drilling and water lifting technologies made it possible to tap deeper aquifers, pump larger volumes of water and lower the cost of water (Vaidyanathan 1996; CAWMA 2007). Groundwater irrigation was the lead input to increase the output per unit of cost with the advent of new varieties of HYVs and fertilisers. Productivity and cropping intensity was high in groundwater irrigation compared to surface irrigation because of two reasons – groundwater irrigation contributed less to conveyance losses and increased water use efficiency; groundwater irrigation provided flexibility in access to water and the timing of water application which

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was not possible in the case of state-controlled surface water irrigation systems (CAWMA 2007).

This intensification of groundwater irrigation, influenced by the government's policies of supporting private groundwater development was, until recently, highly acclaimed. However, now there is a growing apprehension that these policies have resulted in over-exploitation of groundwater. The evidence from all over the country indicates that the progressive lowering of water table threatens its reliability and sustainability for future use (Bhatia 1992; Moench 1995; Dhawan 1995; Shah 1993; Janakarajan 1997; Chandrakanth and Arun 1996; Nagaraj 1994; Nagaraj et al 1995; Shivakumaraswamy and Chandrakanth 1997; Reddy 2003; Janakarajan and Moench 2006; Palanisami 2008; Anantha and Raju 2008). The state and central groundwater departments have been indicating that there is constant increase in the number of over-exploited blocks across the country. Deb Roy and Shah (2003) cautioned about the effects of resource depletion and degradation in the near future. They noted that if the dark and overexploited blocks continued to grow at the present rate of 5.5 per cent per annum, by 2017-18, roughly 36 per cent of the blocks in India will face serious problems of over exploitation of groundwater resources. Similarly, the issue of increasing cost of pumping due to overexploitation of groundwater in recent years is drawing attention (NRC 2004; ESCAP 1987; Deb Roy and Shah 2003; Shivakumaraswamy and Chandrakanth 1997).

The decline in the water table is associated with an increase in well density and a progressive increase in the depth of wells. The progressive lowering of the water table has important socio-economic and ecological implications. As the number of wells tapping an aquifer increases and becomes deeper, the volume of water extracted is not likely to increase in the same proportion. This has negative implications on the yield of the wells and cost per unit of water extraction. After a point, the yield of a well goes down and in the cost of lifting per unit of water from deeper aquifers increases. Progressive lowering of the water table also increases the operation cost of lifting water from deeper aquifers. The severe decline in the water table due to well interference and increase in depth also results in frequent failure of wells. In sum, the cost per unit of water extraction increases for the individual farmer and the society as a whole. This leads to inequality among farmers in accessing groundwater resources due to unequal
capacity to mobilise resources for drilling and deepening the well and pumping water. In this situation, resource poor farmers lose out to the wealthier farmers.

It is in this context, the following questions arise: What is the condition of groundwater irrigation in the state which is second largest arid region of the country? What is the level of groundwater use in agriculture and what are its determinants? Does groundwater overdraft affect livelihoods of farm households? Do externalities that arise from groundwater overdraft affect the welfare of the agrarian community? What mechanisms are adopted by farmers to cope with these problems?

Against this backdrop, this study sought to address the questions by framing the following objectives: To find out the level of groundwater use and its determinants; to assess the impact of groundwater use on the living condition of farm households; and to analyse the implications of groundwater overdraft on environment. To analyse these objectives we formulated a broad hypothesis: cumulative interference of irrigation wells leads to negative externalities.

To analyse this hypothesis, we first formulated an index of cumulative well interference (ICWI) taking into consideration of all the taluks in Karnataka. To calculate the ICWI, we considered the cumulative number of wells and net annual groundwater availability, which will indicate the utilisable quantum of groundwater for all purposes in a particular year for each taluk. Thus, the ICWI was calculated, which explained the number of wells per hectare metre of utilisable groundwater in each taluk. This was a proxy for cumulative well interference. The taluks were then sorted in descending order of the magnitude of the above index. The taluks were later classified according to agro-climatic zones of the State in order to obtain the variability in groundwater use across crop, soil and climatic types. Among the agro-climatic zones, the eastern dry zone topped with respect to ICWI, followed by the central dry zone, the northern dry zone and the southern dry zone, which had an ICWI magnitude above one. However, we decided to choose the taluk which topped with respect to ICWI in one out of ten agro-climatic zones and which does not have substantial surface irrigation projects. The agro-climatic zone chosen was the Central Dry Zone. The selected taluks were Madhugiri and
Hosadurga in the Central Dry Zone and the rationale for selecting them was based on highest and lowest magnitude of ICWI, respectively.

To select the villages in these taluks, the village-wise availability of groundwater for irrigation was computed by using a ratio calculated as follows: Net Sown area of the village divided by net sown area for the taluk multiplied by utilisable groundwater of the taluk. The villages were then sorted in descending order of the magnitude of this ratio. The villages were later selected in order to obtain variability in groundwater use across crop, soil and climatic characteristics. The selected villages represented high and low magnitude of groundwater availability in the respective taluks. The third stage of sampling covered the selection of well owners. In each selected village, by using the Participatory Rural Appraisal (PRA), the number of wells (both functional and non-functional), well depth, distance between wells, farm size and farmer's name was mapped. The PRA method was helpful in locating irrigation wells in relation to cumulative well interference. Using the PRA map, a sample of 225 farmers who had irrigation wells that were densely placed, was drawn from nine villages in the two taluks. This information was based on the knowledge of the well owners who knew the problem of well failure due to the interference problem. Additional information regarding history of well irrigation and other details was collected from village informants to find out the importance of groundwater irrigation and nature of its depletion in the region.

**The context**

Karnataka is a second largest dry land agricultural economy next to Rajasthan. It is predominantly covered with hard rock terrain, varied rainfall and low groundwater potential. These areas have non-porous rocks; the igneous and metamorphic rocks, expected to store not beyond 10 per cent of the annual rainfall. Similarly, the region is endowed with limited surface water sources which increases demand for secure and stable source of water for sustainable rural livelihoods. In view of this, groundwater resource development gained currency and a major portion of India's groundwater irrigation wells is in the hard rock areas. Since agriculture is the major water consumer, it has contributed to food security and promotion of rural livelihoods. In hard rock areas groundwater irrigation, due to its flexibility, has helped in commercialisation of farming through crop diversification and specialisation in high value water intensive crops.
Groundwater development in the state was largely due to institutional failure. The present institutional system only promoted resource exploitation through several programmes and policies. The rural electrification programme, which was largely funded by the state, together with liberal loan assistance on concessional terms for setting up of bore wells and subsidised supply of energy contained the increase in private costs. Till recently, groundwater development was widely acclaimed for its benefit-cost ratio. However, the increasing evidence of progressive lowering of groundwater tables in several parts of the country revealed that the government's policies on groundwater development are at stake (Bhatia 1992; Shah 1993; Dhawan 1995; Janakarajan 1996; Chandrakanth and Arun 1996; Nagaraj et al 1995; Shivakumaraswamy and Chandrakanth 1997; Reddy 2003; Nagaraj et al 2004; Palanisami et al 2008; Anantha and Raju 2008). According to the central and state groundwater organisations, the intensity of groundwater exploitation has reached, or even exceeded, sustainable levels in the development blocks (DMG, GoK 2005).

In Karnataka, nearly 42 per cent of the area is overexploited. As the wells tapping an aquifer increase in number and become deeper, the volume of water extracted is unlikely to increase in the same proportion. Large blocks in the state are in that position of resource extraction. Thus, after a point, the yield per well declines and the investments incurred on lifting per unit of water increases (Nagaraj et al 2004). The operation cost per unit of water also increases because it has to be lifted from a greater depth. Most importantly, the energy needed to lift water from deeper wells increases tremendously. Since electricity is the chief mode of energy to lift water in most of the hard rock areas, the demand for electricity will shoot up to random levels.

The progressive lowering of water tables not only affects the economic condition of farm households but also undermines the welfare of households because the aquifer is shared by many and each unit that is extracted by one farmer is no longer available to others. The only way to lay claim to a unit of groundwater is to pump it. Other farmers too have the same access to the stock and there is little incentive to save water for future use. Hence, farmers will pump inefficiently large amounts of groundwater. The individual user does not consider the detrimental effect of pumping on other farms, so again there
is an incentive to over extract. Since each user will only consider his own extraction impact on the stock, he has a motive to over-exploit and impose external costs on all other users of the same aquifer. It destabilises socio-economic and ecological security. In this context, this study analyses the major objectives put forwarded above.

**Findings of the study**

**Extent of groundwater exploitation in Karnataka**

Groundwater has emerged as a productive resource in view of the limited supply of surface water and scanty rainfall in Karnataka. Nearly half of the irrigated area in the state is under groundwater irrigation. The compound growth rate of net irrigated area reveals that the progress in terms of groundwater irrigation development was quicker than that of surface water. There is a positive change in terms of canal irrigation due to the recent investment made by the government in canal irrigation. However, surface irrigation as a whole has shown a mixed trend in terms of contribution to net irrigated area. Irrigation as a percentage of net sown area by tank decreased. This could be due to several reasons - Karnataka is historically dependent on tank irrigation, but the region may be going through a phase wherein the old traditional collective system of tank management is collapsing with newer organisations yet to be established. It is important to note that the share of open well irrigation in net sown area declined while area under bore well irrigation increased. This indicates that farmers increasingly resorted to groundwater irrigation through bore wells as a result of progressive lowering of groundwater tables. The area under canal and bore well irrigation showed positive change over a period of time while other sources registered negative changes because of old community ownership and management shifted towards market-oriented management mechanisms and technological innovations leading to the emergence of deeper bore wells ingesting larger quantities of groundwater reserves. As a result, the total resource of the over-exploited watersheds in the state was 0.38 m ham as against the draft of 0.60 m ham thus accounting for an over draft of 0.22 m ham.

The state has witnessed three stages of groundwater development since the 1950s. Each stage was unique in character, from dug wells to very deep bore wells fitted with submersible pump sets. The change in irrigation technology was also accompanied by changes in the cropping pattern. As bore well technology became widely available, the
irrigated area expanded intensively with water intensive crops. This improvement was associated with several socio-economic as well as ecological implications. The irrigation intensity, an indicator of agricultural efficiency, reveals that the potential of irrigation has been declining marginally over a period of time indicating that the expansion of irrigated area could result in a negative marginal increment.

The response of the state to check groundwater exploitation was in terms of policies to increase supply and curtail demand. These policies include direct and indirect forms of regulations. Adoption of the model bill and creation of regulatory authorities were the direct forms of regulation to check over exploitation of groundwater. The control on institutional finance was an indirect form of regulation. Unfortunately, the indirect form of regulation was inequitable in its effect on access to groundwater resources for the poor marginalised farmer. Neither the direct nor the indirect forms of regulations were helpful in checking the over-exploitation of groundwater in the state. Therefore, exploitation of groundwater resources for private gains continued.

**The level of groundwater use on the farm and its determinants**

Groundwater offers a potentially viable alternative to surface irrigation because of its limited capital requirement and low recurring cost. In addition, farmers can better control the use of groundwater for more timely supply of water relative to the surface water schemes. Hence, the area under groundwater irrigation has been expanding drastically leading to aquifer depletion. The expansion of groundwater irrigation is due to improvements in the technology of drilling and lifting water that made it possible to tap deeper aquifers. Therefore, there was a shift in the cropping pattern towards water intensive high value crops.

It was in this context observed that the degree of groundwater utilisation varied across crops and seasons. The results indicate that the groundwater was a prerequisite for establishing the crop. Hence, the extraction and utilisation of groundwater resource was attributed to scanty rainfall and limited surface water sources and cropping was mainly governed by access to groundwater. Bore wells with submersible pumps were the only sources of irrigation. The variation in groundwater use for different crops implied that the crop type, moisture condition, soil type and climatic condition played important roles.
in the volume of water application. Therefore, the results also indicated that the short
term food crops were consuming more water than the perennial crops.

The econometric model used explains the level of extraction of groundwater to irrigate
the farm. The quantity of water used will decline when pumping cost increases. Cost of
pumping water plays a major role in extracting water for irrigation. The increasing
operation and maintenance costs increase the pumping costs in general due to its
implicit characteristic in irrigation cost. Pumping cost is the major factor which
determines the amount of water used on the farm. The increasing pumping cost implies
that an increase in the cost of pumping could be associated with a decrease in water
use.

An important observation of the study was that the net return negatively influenced
water use on the farm. This implies that the high water intensive crops accounted for
lower returns than the less water intensive commercial crops. It also suggests that there
is a need to create awareness among farmers about the cropping pattern as well as
market facilities. The government should provide appropriate storage facilities for
agricultural goods so that farmers feel secure about their products and accordingly shift
the cropping pattern towards water efficient crops. It is obvious that the water intensive
crops are consuming more water leading to more demand for groundwater. In spite of
high water consumption, paddy is more predominantly grown in HWIA adding to the
scarcity problem. Therefore, the cropping pattern should shift to less water intensive
annual crops such as ragi, groundnut and other cereal crops and reduce the stress on
groundwater in order to maintain the balance between supply of and demand for
irrigation.

The level of groundwater use on the farm mainly depended on the cropping pattern,
landholding size, method of irrigation application and seasonal factors. Food crops are
hydrophilic, demand more water and add to resource scarcity equation. The fact that
the level of groundwater use is significant enough to affect income from irrigated
agriculture and impact livelihood, wider societal and political concern is essential to
prevent over exploitation. Use of water inefficient conveyance systems also contribute to
making groundwater use in agriculture more inefficient and unsustainable. Although the
cultivation practice has been spread across all the seasons, the intensity of crop cultivation is limited to the kharif season.

**Groundwater overdraft and rural livelihoods**

The recent water scarcity problem was due to the democratic nature of its exploitation without improving the replenishing capacity of the aquifers. Moreover, the development of groundwater is in the hands of farmers leading to decentralised development. Many researchers argue that groundwater irrigation minimises the gulf between resource rich and resource poor farmers by providing opportunities to irrigate their land. Therefore, access to groundwater improves the livelihood of millions of small farmers. Access to adequate groundwater also improves the livelihood of rural agricultural and non-agricultural labourers by providing year-round employment. However, progressive lowering of the water table undermines the above mentioned water-livelihood consonance. The declining groundwater resource affects the development of irrigated agriculture. The problem of groundwater overdraft affects the chain of development. It triggers the cost of drilling. Resource poor farmers are unable to cope with the problems of water scarcity while resource rich farmers can cope up the problems by investing in well deepening and drilling additional wells to get reliable yields adding to resource scarcity problem. This undermines the livelihood opportunities of small and marginal farmers to a large extent.

In this context, we analysed the economic viability of groundwater irrigation due to groundwater overdraft and its implications on farmers’ livelihoods. The two case studies we considered for detailed study revealed that the resource scarcity problem due to cumulative well interference was severe in HWIA where the cropping pattern was water intensive. Importantly, the depth of the water table had reached a critical level signaling irreparable negative externalities on further exploitation. In LWIA, the low water intensive cropping pattern was a coping mechanism to reduce the risks of cumulative well interference. Although the resource scarcity problem was temporary and unpredictable, it was severe in HWIA leading to inter and intra-generational equity impact on the farming community. Most importantly, the economics of groundwater irrigation was deteriorating due to the rapidly declining water table. The annual irrigation cost was soaring in HWIA leading to unsustainable growth of groundwater
based agriculture. The rise in the annual irrigation cost was on account of two major factors - progressive lowering of the water table and poor quality of electricity supplied for irrigation purposes.

The groundwater and livelihood consonance was deteriorating due to declining resource endowment. Thus, area with high resource scarcity faced high incidence of well failure, escalating cost of resource extraction and utilisation, low and negative net returns and reduced contribution to the rural livelihood system. Agriculture continued to be one of the preferred livelihood strategies in all the study villages due to lower share of non-farm income which had low effective demand. However, low private net returns from well irrigation were worrisome in all the study villages. Interestingly, the lion's share of the agricultural value product generated from groundwater irrigation was from low water intensive crops such as coconut, groundnut and other cereal crops. However, depletion of groundwater and changes in water table conditions had resulted in a sharp increase in the cost of irrigation and reduced private net returns from groundwater based farming. The annual size of groundwater economy varied across villages owing to groundwater resource availability, cropping pattern and climatic condition.

The high probability of well failure increased the debt burden of the household substantially. This had spillover effects on the rural agrarian system. The debt burden measured in terms of debt-asset ratio was substantially higher in HWIA. The size of landholding, cropping pattern and climatic condition forced farmers in this region to lose their asset pyramid. The livelihood index prepared based on irrigated agriculture in LWIA is higher than HWIA indicating the role of irrigation in rural livelihood system. The low rate of livelihood impact in HWIA indicated that water scarcity was severe and made the farming community vulnerable.

**Externalities associated with groundwater overdraft**

The externalities are the outcome of individual efforts to make profit by affecting the utility function of others without any compensation. In the context of the groundwater economy, the externalities occurred because an aquifer could be shared by many and the quantity of water available to one person may not be same for others. This influenced competitive extraction among farmers leading to the problem of cumulative
well interference. When water tables fell, the probability of well failure increased and resulted in loss of associated capital costs of groundwater extraction.

In the above context, the study examined externalities associated with groundwater over-exploitation. The results indicate that the severity of groundwater over-exploitation is a threat to its sustainability in both areas. The comparison of LWIA and HWIA in terms of major indicators of groundwater over-exploitation presents a gloomy picture. The investment scenario of well irrigation suggests that the groundwater irrigation suffered as water table decreased constantly. There was increasing competition among farmers to obtain sustainable yields. Farmers sunk many wells to reach the economic optimum of groundwater irrigation. However, since the well failure rate was increasing in view of decreasing water table, the investment in bore wells remained unproductive. The incidence of well failure due to cumulative well interference was high in HWIA. Not all the farmers who had invested in wells were successful. Many lost the race. They had to bear the risk of failure in locating productive zones. Many landowners were trapped in debt after trying to develop new wells with informal credit.

The LWIA was comparatively better off in terms of resource exploitation while HWIA was worst hit. As irrigation became less reliable, productivity declined and the associated risks of loss increased. The results indicate that the replacement cost in terms of drilling additional well had a severe impact on the household economy and the micro environment. At the current level of resource extraction, the additional burden on the farming household would be much larger than what is evident at present. The total negative externality cost for the sample farmers was colossal. The negative externality cost in HWIA was more than three times that in LWIA. The large gap between LWIA and HWIA was due to physical as well as economic scarcity of groundwater resources.

Efficiency in groundwater use per farm was estimated by comparing the economic optimum use with actual use. The results indicated that optimal groundwater was high in LWIA than the actual water use while the optimal groundwater use was lower than the actual water use in HWIA. This implies that the groundwater extraction in HWIA was beyond the replenishment capacity of the aquifers. The cost per acre-inch of water extracted (marginal cost) was highest for HWIA and the lowest for LWIA. The marginal
return (MR) of groundwater was higher by 19 per cent over HWIA. The ratio of marginal return to marginal cost was highest for LWIA compared to HWIA. The elasticity of returns with respect to water use was highest in LWIA indicating the efficiency in water use was relatively better compared to HWIA.

**Environmental problems**

In hard rock areas well density reached the maximum level leading to severe groundwater depletion of both unconfined and confined aquifers. The depletion of aquifers was a severe setback to groundwater dependent ecosystem. Persistent groundwater exploitation in excess of natural recharge induced serious environmental problems in these areas. The progressive lowering of the water table was one of the major sources for the degradation of surrounding ecosystem. The rapidly declining water level was a significant outcome of groundwater over-exploitation and the cumulative well interference problem. As a result, the recharging capacity of surface water bodies deteriorated over time. As groundwater level declined, the water quality became a major issue for drinking water purposes.

The results indicated that the average depth to water increased from 200 ft in 1986 to 240 ft in 2007 in LWIA and from 338 ft to 490 ft in HWIA indicating the severe impact on the ecosystem and dependent sectors. In the initial stage of exploitation, wells were near the land surface. However, the persistently high rate of groundwater withdrawal led to a water levels declining by one to two meters annually in the 1990s and to the formation of large cones of depression. The perception of the sample farmers indicated that the severity of groundwater depletion in surface water bodies such as tanks was critical.

**Welfare impacts**

The exploitation of groundwater is a problem of common property, since there is limited access to the resource. If each user is a profit maximizing agent, there are a number of reasons for the inefficiency of a private solution. The fact that there is a finite stock means that each unit that is extracted by one farmer is no longer available to others. Given that the only way to lay claim to a unit of groundwater is to pump it, there is little incentive to save water for later use, since other farmers have the same access to the
stock. Hence farmers will pump an inefficiently large amount of groundwater. Moreover, pumping costs generally depend on the level of the water table, which means that as the groundwater stock declines, extraction costs rise. However, the individual user does not consider the detrimental effect of pumping at the cost of other farmers, so again there is an incentive to over exploit.

In the above context, this study examined the welfare effects of groundwater over-exploitation. Results indicate that the external costs or social cost generated by well owners was higher in HWIA compared to LWIA. This indicates that the users behaved myopically in view of obtaining sustainable yield through competitive deepening of wells. The social cost per well in HWIA was 51 per cent higher over LWIA and small farmers are the worst sufferers. Excess water pumped was highest for large farmers in LWIA while that of small farmers in HWIA. This conflicting result indicates that the myopic nature of groundwater extraction by farmers.

The annual average estimated welfare loss due to groundwater depletion was colossal. The HWIA was a major paddy producer for consumption purpose. The drive for self-sufficiency in this strategic crop, encouraged by subsidised power supply and easy access to drilling technology placed heavy pressure on the quantity and quality of groundwater resources extracted in HWIA. In LWIA, a low water intensive cropping pattern coupled with the adoption of micro-irrigation techniques reduced the pressure on the groundwater resource and resulted in relatively low welfare loss. However, landholding size does not seem to be a contributing factor for the deteriorating welfare condition in LWIA where the aquifer condition was better than that of HWIA.

The equity effect of groundwater over-exploitation is one of the major externalities in groundwater irrigation. The results indicated that the resource scarcity was the cause and effect of the emerging equity concern in these areas. The groundwater predicament assumed greater dimension due to the farmers’ apathy towards resource management and increase in the number of wells. The rapid exploitation of groundwater to support high value crops resulted in reducing the number of successful wells to half of the total wells owned per farm. This has an inter-generational equity issue since groundwater development was largely undertaken by the private initiatives of the farmers.
Coping mechanisms
Overexploitation of groundwater resource was evident in different degrees in the study area. The high degree of groundwater exploitation was a major threat to its sustainability and equity leading to inefficiency in the resource use pattern. Groundwater based agriculture can hardly be sustained given the current rate of resource development in the study region. Added to this, the groundwater resource status is also deteriorating leading to bankruptcy of aquifers. The overexploitation of groundwater in the study area was largely due to institutional failure. The existing institutional arrangement promoted over exploitation of aquifers and failed to generate adequate incentives for the adoption technologies for efficient use of water. Therefore, farmers themselves used several mechanisms to cope with water scarcity problems. These mechanisms varied from drilling additional wells to shifting cropping patterns to water efficient crops. It is important to note that these mechanisms varied according to the degree of resource depletion. A majority of farmer actively involved in adopting coping mechanisms. The small farmers adopted less capital intensive coping mechanisms while large farmers adopted capital intensive measures. In HWIA, since the degree of groundwater overdraft had reached critical levels and posed a severe threat to its sustainability, the cost of coping mechanisms was higher than in LWIA. The adoptin of different conservation practices by different categories of farmers in the areas where groundwater has been over-exploited supports the hypothesis that over-exploitation of groundwater has differential impact on these farmers.

Implications of the study
The findings of the study will have both theoretical and policy implications. In the ensuing sections, we will discuss these implications.

Theoretical Implications
Based on the empirical results, various theoretical implications can be drawn. The consequences of groundwater over-exploitation show that resource scarcity caused by competitive extraction leads to deterioration in the marginal value productivity of water in agriculture. Therefore, enhancing water productivity is the key to realizing higher marginal value of water in agriculture. That would strengthen rural livelihood system through high economic gains from per unit of water used on the farm.
The scarcity of groundwater in the study area increased its economic value. Both the value of the marginal utility and the total utility of irrigation water in crop production was determined by the water deficit experienced by the crops at any point of time which was a function of the agro-climatic condition and the type of crop grown – whether high or low value. The total and marginal utility of water in irrigated production can be enhanced through efficient use of water and other inputs, or through shifts in cropping pattern to more water efficient crops with intensive cropping. Therefore, when demand for irrigation water exceeds supplies, farmers should divert it for high value uses, or use it more efficiently through on-farm water management or farm management or better crop technologies because both the total and the marginal utility of irrigation water would be high.

Water control alone can bridge the gap between potential and actual yields by about 20 per cent (Herdt and Wickham 1978). Thus, reliability rather than just availability is one of the most important factors to enhance agricultural yield (Moench 2003). In the study area when opportunities for increased exploitation of groundwater became elusive, agriculture encroached upon fragile ecosystems that could not be further exploited. Without the necessary resource-improving investments, groundwater irrigation deteriorated and over-exploitation of groundwater destabilised the agrarian economy.

The present study has found that the externalities arises from groundwater over-exploitation are severe and occurred in different degrees in LWIA and HWIA. Therefore, the results might have been better if the interventions by the state in the form of mechanisms to recharge groundwater or management of existing surface water bodies. We found that the estimated negative externality cost and the corresponding welfare loss due to occurrence of failed wells was colossal. This was due to less attention paid to the issue of groundwater recharge and the competitiveness among farmers over groundwater extraction leading to low well yield and high rate of well failure. There is little incentive to save water for later use, since other farmers have the same access to the stock. Hence, farmers will pump an inefficiently large amount of groundwater. There were limited efforts to shift cropping pattern from water intensive to water efficient crops and use water saving technologies. This has further implication for the sustainability of groundwater resources.
**Policy implications**

Based on the analysis carried out and conclusions arrived at in the study, certain policy implications have been drawn. The policy implications that emerged from the study relate mainly to four aspects: (i) regulatory interventions; (ii) demand and supply interventions; (iii) technological interventions; and (iv) strategic interventions.

**Regulatory interventions:** The findings of the study suggest that inappropriate management of groundwater resource led to present level of over-exploitation in the state. The increasing well density or cumulative well interference was due to lack of property rights over groundwater. However, lack of efforts in maintenance of inter-well space, proper permits for drilling wells, use of efficient pumping technology and optimum number of wells are the major factors contributing to groundwater over-exploitation. Apart from these private initiatives, state policies such as subsidised electricity for agricultural pump sets had an adverse impact on groundwater development. Therefore, the study calls for a holistic approach to institutional restructuring of groundwater regulations through appropriate institutional arrangements.

- First and foremost groundwater legislation should incorporate the cumulative policy pronouncements made both at the national and the state level concerning water, agriculture and the economy. There shall be specifications regarding isolation distance and/or isolation depth/s linked with water use technology (like drip or sprinkler). It should be understood that isolation distance/depth cannot be enforced, since there can be no blanket isolation distance/depth in hard rock areas where groundwater access varies vastly.

- In addition, it is difficult to have accurate specified distance between two wells. Instead, a cap on the number of irrigation wells is a reasonably easier to measure and/or regulate. Water conservation through rainwater and roof water harvesting must find a place in the new legislation. Similarly, recharge measures need to be indicated and encouraged for different agro-climatic regions.

- To improve groundwater efficiency on the farm, micro-irrigation technologies that make groundwater in agriculture more efficient and sustainable should be used. Besides, water efficient cropping needs to be practiced by providing the necessary
infrastructure such as roads, transport, marketing, storage facilities etc., so that farmers can diversify the cropping patterns based on local conditions.

Creating effective market demand for agricultural products might influence farmers to allocate part of their income for water saving technologies. This might reduce the pressure on groundwater resources and at the same time improve the resource base.

**Demand and supply side interventions**: Groundwater over-exploitation is also the result of commercialisation of agriculture. Groundwater development has provided crop diversification through the democratic nature of its exploitation. Therefore, farmers shifted less water intensive crops to high value water intensive crops such as paddy, vegetables which are hydrophilic, demanding more water. In order to cultivate these crops, farmers ventured into high yielding bore wells drilling deeper depth. This led to a decline in the water tables. Therefore, groundwater over-exploitation is also attributed to the cultivation of water intensive commercial crops on a large scale. Hence, there is a need for a benevolent cropping pattern which consumes less water. The results also indicate that there are voluntary initiatives by farmers to shift cropping pattern to less water intensive tree crops such as mango and other fruits. These farmers need to be motivated with appropriate incentives to strengthen their economic condition and the resource base.

The supply side interventions are necessary to augment groundwater supply. The study shows that no efforts were made to augmenting the supply of groundwater and hence, there is large gap between extraction and recharge. Thus, efforts should be made to bridge the gap between extraction and recharge for the construction of water harvesting structures, rainwater harvesting etc., through community participation. The role of the state is necessary in terms of rejuvenating existing tanks, ponds and streams to augment groundwater. The specific policy suggestions are as follows:

- Appropriate incentive mechanisms have to be evolved in terms of marketing, storage, and transport facilities for farmers interested in shifting their cropping pattern from water intensive to water efficient crops. Efficient pricing mechanisms for the products will promote the cultivation of water efficient crops.
- Rejuvenating traditional water bodies will promote groundwater recharge and bridge the gap between extraction and recharge. This not only improves the groundwater
resource base but also promotes water dependent rural livelihood system by making way for non-farm activities. Hence, diversification of the rural agrarian economy.

- There is a need to protect the ecosystem services by strengthening the groundwater resource base through augmentation of supply. In this context, the watershed management practices which have proved to be an effective means of recharging groundwater, improving soil fertility, and enhancing productivity should be implemented especially in arid and semi-arid regions.

- Incentives for farmers on resource utilisation should be linked to the use of water saving technologies (e.g. drip/sprinkler) and water conservation (e.g. farm ponds/rainwater harvesting structures) mechanisms. This type of community/collective management of groundwater resource will improve equity in access to water and sustainability of the resource. Similarly, social regulation over groundwater use is necessary to counteract over exploitation which minimises the pressure on groundwater.

- Non-farm activities that are water efficient or require less water such as dairy or horticulture should be encouraged to improve water and livelihood consonance. Non-farm production should be encouraged by providing market facilities at the local level such as village or community to diversify the local production system.

**Technological interventions:** The declining water use efficiency is of serious concern, mainly due to the increasing demand for water and rapid decline of the available water. The flood method of irrigation is in practice predominantly leading to low water use efficiency and enormous losses in distribution and through evaporation. The recently introduced drip method of irrigation helps increase water use efficiency significantly. Thus, promotion of drip irrigation and other types of micro irrigation techniques would help to reduce the risks of losses and reduce the pressure on the resource. The method of irrigation followed in LWIA is a reflection of the crop pattern which allows use of modern water saving technologies such as drip irrigation which assumes greater significance for its comparative advantage over other methods. However, drip irrigation is a costly affair and small and marginal farmers cannot afford to invest in it. Further, short term food crops were not allowed to use drip method owing to many difficulties. Therefore, in HWIA the flood method was the most preferred mode of irrigation although water scarcity was of concern. In HWIA, the flood method of irrigation caused
huge quantities of water to be wasted and added to existing scarcity problem. Therefore, the ideal solution would be to introduce water efficient remunerative crops.

✓ Repair and revival of traditional water harvesting and conveyance structures and community based management systems is the need of the hour.

✓ Incentive packages have to be provided to farmers to adopt micro-irrigation techniques. Improved agriculture and irrigation practices must achieve ‘more crop per drop’. Promotion of water conservation methods such as sprinkler and drip irrigation, investment in on-farm works and other land-improvement equipments and technologies should be encouraged.

**Strategic interventions**: The increasing inequity in access to groundwater results in deterioration of the living conditions of the poor farmers. However, the initial stage of groundwater boom was guided by large and medium farmers because they could afford to drill deeper wells and use new technologies. Because of the large investment requirements, large and medium farmers were among the first to opt for bore wells. Spacing and other norms and regulations that came into recently excluded the poor who comes into the groundwater game at a later stage. Therefore, strategic intervention by the government to augment supply of groundwater and facilitate resource extraction by poor farmers is required. The following policy suggestions could be viable options for strategic interventions.

✓ Augmenting supply of groundwater through aquifer recharge activities such as watershed management practices, rainwater harvesting programmes and other recharging activities.

✓ Since all externalities associated with private exploitation arise primarily because losers find it impossible to extract suitable compensation from the emitters of the externalities under the existing structure of property rights, public control over water resources by a well informed and just authority will result in effective elimination. The proposed spacing regulations tend to exclude the late comers and create and strengthen the monopoly of existing owners. In other words, spacing regulations single out the poor to bear the cost of maintaining the ecological balance. Therefore, adequate and acceptable interventions by the government to augment supply of water and its management could solve the inequity that persists in groundwater extraction.