SUMMARY AND CONCLUSION

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With a market oriented shift in the cropping pattern from food crops to commercial water-intensive crops, the demand for groundwater has escalated sharply. Further, with the introduction of modern extraction mechanisms, the groundwater extraction scenario has reached to a stage of no return. The subsidized electricity to the agricultural pump-sets has drastically reduced marginal extraction cost and acted as a strong incentive to go for more wells and draw a greater volume of water for meeting the increased demand of commercial agriculture, thereby, further lowering the already low groundwater table in many parts of the world. These have different implications for different segments of farming community.

While much of the debate on green revolution, also called Tube well revolution by some scholar, has concentrated on Paddy – Wheat system, the issue of groundwater use by other cropping systems in semi-arid tropics has been sparsely covered in the literature. The demand management strategy for groundwater, particularly in agricultural use, warrants understanding the groundwater extraction pattern in the context of the crops and the cropping systems in different geo-hydrological settings for ensuring a sound policy intervention.

Towards this end, the present study contributes by examining the pattern of groundwater extraction vis-à-vis the cropping systems, identify crops and crop combinations in terms of their water extraction level and examine their water productivity, inter-season as well as intra-season. A rational use of irrigation water in crop, particularly the groundwater has been attempted based on economic theory to draw implications for resource sustainability. Finally, a deterministic control approach in quadratic linear problem framework has been applied to examine the response of groundwater system to different groundwater extraction scenarios to draw implications for groundwater availability.

The results can be summarized as under,

i) The annual groundwater extraction and cropping systems practiced in the tube well command has statistically significant relationship.

ii) Not only the annual groundwater extraction and the cropping systems practiced in the watershed are related but also, in general the mean groundwater extractions estimated from the model are significantly different among the cropping systems.

iii) Cotton and cotton based cropping systems are the major cropping systems followed in the watershed. The mean annual groundwater extraction level varied from 19 m^3acre^{-1} in cotton + maize inter crop to 13440 m^3acre^{-1} in cotton-castor-fennel-cumin-summer pearl millet cropping system.

iv) During the higher rainfall year, the cropping systems with significantly higher groundwater extraction than the average extraction in the watershed, included more number of crops, in addition to the cotton as compared to that in lower rainfall year.

v) Farmers exercised caution in the extraction and use of groundwater with varying expectations about assured groundwater availability based on the rain fall pattern over the years.

vi) A general trend clearly visible in the watershed about farmers' preference of crops was more number of crops in the cotton based system with more availability of groundwater.

vii) Not only the cropping system practiced in the tube well command significantly varied with the water table in the tube well but also the annual average depth to water table was affected by the cropping systems, farmers take in the corresponding tube well command. The latter relationship being stronger than the former.

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The Discriminant analysis revealed distinct groups in terms of significant discrimination as under,

a) Cotton and cotton based cropping systems formed one distinct group during all the years.

b) Non-cotton based cropping systems formed another distinct group as during 2004-05.

c) Among mono crops, cotton mono crop and others such as paddy, castor, fennel, cumin and summer pearl millet mono crops individually formed distinct groups.

d) The non-cotton mono crops taken together did not form one distinct group as these were not significantly different among themselves.

The results of cluster analysis are summarized as under,

a) In a years of normal rainfall (2003-04 and 2004-05), the mono crops such as paddy, fennel, summer pearl millet and sunflower formed one group, while double cropping system such as cotton-fennel, cotton-cumin, cotton-sunflower formed another group. Cotton mono system was altogether a separate group.

b) The exceptionally high rain fall year (2005-06) revealed a different trend. Firstly, the number of crop combinations tried by farmers increased as compared to the crops grown in the previous normal year, though as in the normal rainfall year, cotton based cropping systems formed a distinct group. Though most of the mono crop and double crops formed separate groups, some were distributed in different groups.

c) The analysis of pooled data (2003 – 05) indicated that cotton mono crop, cotton-fennel, cotton-cumin and cotton-castor clearly dominated and formed one group. These crops and crop combinations are distinct in groundwater extraction also. Therefore, manipulation of irrigation water use in these crops, based on water productivity, has implications for water saving in the watershed.

The marginal productivity framework revealed that in cotton crop marginal water values ranged from 5 Rs./m^3 to 7 Rs./m^3. The marginal water values in castor were at par, rather slightly higher (7 Rs./m^3 to 10 Rs./m^3). Among *rabi* crops, cumin fared better than wheat and summer pearl millet crops. The marginal value of water in cumin was in the range of 35.00 to 41.00 Rs./m^3, in comparison to wheat (1 Rs./m^3 to 3.00 Rs./m^3) and summer pearl millet (2.00 to 4.00 Rs./m^3) at different crop growth stages in different seasons. This framework can be used to suggest inter crop and the intra crop redistribution of the groundwater with implication for groundwater saving. This analysis along with the analysis done in the previous section can be summarized as under,

a) The marginal productivity of water revealed cotton to be a poor competitor for groundwater use as compared to castor and cumin.

b) The strong relationship between cropping systems practiced in tube well command and the marginal productivity of water use in crops clearly make a strong case of gradually shifting area under crop like cotton to other remunerative crops like castor and cumin. In the later crops marginal water values indicated that groundwater use not only made economic sense and could effect substantial saving in groundwater use.

Farmers of the watershed seem to have preference for cotton and cotton based cropping systems. It has been revealed that with increased groundwater recharge, as a result of high rainfall, and therefore, availability of more groundwater, farmers increase more number of crops in the cotton based cropping system. This has resulted into more groundwater being extracted in the watershed. Higher extraction of groundwater can affect adversely the buffer role of groundwater stock in the event of the following year being rainfall deficit. Optimum path of groundwater table trajectory was, therefore, tracked in response to changing groundwater extraction scenarios in quadratic linear problem framework.

The main conclusions of the analysis are as under,

1) Up to 1 per cent increase in groundwater extraction, the groundwater system is quite stable as the desired path of groundwater table is also the optimal path. As the groundwater extraction rate increased to 5 per cent, optimal path water table started declining as compared to the desired path. A further increase in groundwater extraction rate to 10 per cent or more worsened the situation. This depth of water table coincides with a leaky aquifer as described earlier and is a better transmitting zone. At lower rate of extraction (less than 5 per cent), the water table does not drop sharply. A higher extraction rate (beyond 5 per cent) would lead to decline in water table faster.

2) At 35m depth, the water table declines continuously even at a lower extraction rate of 0.5 per cent. At 10 per cent and 15 per cent, the decline became steeper. This water table depth coincided with another water bearing strata, inter-trappean semi-confined to confined aquifer. The behaviour of this aquifer is quite uncertain in terms of water supply. The analysis revealed that the water table continuously declined as a result wells penetrated to this depth could not be depended for regular groundwater supply.

3) At the groundwater table depth of 50m, the optimal and desired path of groundwater table increase was the same, if the growth rate in groundwater table was kept at 1 per cent or below. At the growth rate higher than 1% in the groundwater extraction, the optimal path drifted from the desired path, the percentage rate of decline in groundwater table increasing with each time period. The depth of groundwater table falls in the lower water bearing strata,

that is aquifer with intermittent mud layer. Wells penetrating to this aquifer do not yield dependable supplies of water up to a sizable increase in groundwater extraction rate. Hence, higher extraction from this depth would drastically affect the groundwater depth.

4) A majority of the wells (60m to 70m) in the watershed extract water from this aquifer and, therefore, dependability of groundwater supply, in the long run, may not be quite reliable. The previous sections proved a close relationship between cropping systems and groundwater extraction as well as the groundwater depth. This has implications for sustainable use of the resource in future.

Quadratic linear tracking framework has not been extensively applied to natural resource problem in general and groundwater use in particular. To that end, the present study has made efforts to understand the response of complex groundwater system to groundwater extraction through a very simple one control and one state variable model. With further extensive data collection, the model can be further refined. While this is a limitation of the study, this leaves scope for future work. The complex economic-hydrologic models have been extensively used by scholars to that end, but application of such models in Indian context is still limited and would require several assumptions to be made for their direct application in real field situations.