REVIEW OF LITERATURE

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2 Overview

Water scarcity issues are a cause for serious concern in arid and semi-arid regions. While the existing water shortages are likely to increase in frequency as well as the duration over the next century, global water consumption has grown six fold between 1900 and 1995, more than double the rate of population growth. The deteriorating water quality caused by pollution has further complicated water scarcity in arid and semi-arid regions. Water management, in general and groundwater management, in particular is, therefore, the need of the hour in such water scarce areas. The present section discusses the various issues related to water resources management studies by the scholars in this field in the country and elsewhere.

Optimization of groundwater use

The work on the economics of groundwater extraction began way back in the late 1950 and 1960 (Miliman, 1956; Renshaw, 1963 and Kelso, 1961). Economic studies of groundwater extraction have covered several areas. Burt (1964, 1966, 1967, 1970) worked on principles of inventory management to derive decision rules for the optimal temporal allocation in a dynamic programming format. It was contested by several scholars that in a scenario of free market, farmers will keep pumping until the aquifer reaches an unacceptable water level (Gisser and Mercado, 1972 and 1973; Cummings and McFarland, 1973). Effects of different policy instruments on the misallocation of commonly owned groundwater have been analyzed by Bredehoeft and Young (1970). Brown and Deacon (1972) derived a formula for a tax that should be imposed on groundwater (pumped) in order to yield the optimal control solution. Brown (1974) recognized the issue of congestion externality in aquifers with open-access characteristics and suggested charging a tax to accommodate this externality.

Scholars (Burt, 1964; Brown and Decon, 1972) have derived optimal control rules for the management of groundwater resources. Sequential decision theory was used to derive optimal control policies (Burt, 1966).

Over time, new scholarly works emerged. The theory of dynamic games provided the possibility of modeling the dynamic interactions involved in the allocation of natural resources and accounted for the fact that most externalities exhibited some form of structural time dependence. Application of game theory was done for the characterization of pumping behavior when the number of extracting players was small. In this, under common property management scenarios, game theoretic models of pumping behavior were developed, where a firm's strategy was the groundwater extraction plan defining its behavior in each period of its planning horizon (Dixon, 1989; Negri, 1989; and Provencher and Burt, 1993).

Comparison of social welfare of groundwater pumping under the two scenarios, central (optimal) control and the private property regime in which the firms are granted tradable permits to the *in situ* groundwater stock revealed that when the firms were risk averse both the regime were sub-optimal (Provencher and Burt, 1994). On the contrary, when the firms were risk neutral, central (optimal) control dominates the private property regime. The empirical analysis with a stochastic dynamic programming model revealed that the private property regime proved to be a better alternative to optimal control, considering the magnitude of the welfare differences between optimal control rules and competitive outcomes (Gisser and Sanchez, 1980 a, b; Gisser, 1983).

Ignoring scarcity rents, in cases where there is no optimal dynamic management of common-pool groundwater resources or in the presence of a competitive extraction, results in inefficient pricing and misallocation of the resource (Koundouri, 2004). Yet the competitive dynamic solution of groundwater exploitation has been proved to be almost identical in terms of derived social welfare with the optimal control solution, known as Gisser–Sanchez's effect (GSE) (Gisser and Sanchez, 1980a, b).

Studies on conjunctive use of surface water and groundwater were first reported by Burt (1964, 1966, 1967, 1970), where he modeled groundwater stocks as partially renewed by a stochastic process. His model considered surface water and groundwater as substitute goods, abstracting from the problems associated with the lagged hydrologic effect present in a tributary aquifer. Burness and Martin (1988) subsequently developed an analytical economic model that focused primarily on the hydrologic link between surface and groundwater, by modeling the instantaneous rate of aquifer recharge caused by groundwater pumping, through river effects. The river effects were modeled as externalities which reinforced groundwater over-pumping due to the usual common property effects. They concluded that optimal policy required compensation to be paid for both river effects and aquifer depletion net of river effects. Some detailed reviews are discussed below,

Brill and Burness (1994) used optimal management model in Ogallala aquifer and found that a 2% annual demand growth led to significant divergence (16.85%) in socially optimal versus competitive rates of groundwater pumping. They supported the thesis that the high social discount rates diminished the importance of (future) pumping cost externalities and produced a convergence between competitive and planned pumping rates.

Bredehoeft and Young (1970) in their study reported the effects of different policy instruments that might correct the misallocation of commonly owned groundwater. They found that net benefits from groundwater management could amount to over $100 per acre with a caution that these benefits would decline with increases in interest rate.

Burness and Brill (2001) used the optimal management of aquifer model to Curry county, one of the five counties covered by the Ogallala aquifer considering an endogenous investment in irrigation technology. However, its numerical simulation revealed only a modest difference between benefits in the planning vis-à-vis the competitive solution. The welfare gains from more efficient water use are offset to some extent by inefficiencies in investment.

Cheesman, (2005) applied a non-linear programming model for optimal irrigation scheduling in Dak Lak area of Vietnam. This model estimated weekly irrigation water allotment for each crop subject to non-linear constraints on crops soil moisture transition functions and linear constraint on land allocation and water availability with the objective of maximizing total net benefits of production. Crop yields, included in the objective function, were estimated from the available soil moisture and irrigation water applied per week which was obtained from a crop response simulation model. The model included three modules, viz., crop response simulation module, crop yield soil moisture relation module, and dynamic economic optimization module. The model had several limitations. First, it did not consider soil or water quality impacts on crop productivity. Second, it did not account for forced crop maturity due to water stress. Third, the model assumed uniform irrigation applications, ignoring potential spatial variability in soil moisture resulting from non-uniform irrigation and/ or heterogeneous soil properties. Finally, the model did not allow for potential changes in yield resulting from inter-cropping or optimal plant spacing.

Chhikara and Panghal (1989) applied linear programming technique to optimize the resource use on different farm situations both at the existing and improved levels of technology in semi-arid tropic area of Haryana state. Significant changes were noticed in the cropping patterns in the optimum plans at both the levels of technologies. Relaxation of capital, labour and irrigation resources further increased the net returns.

Duckstein et al., (1994) applied multi-criterion decision making (MCDM) techniques to a typical ground-water management problem. Criteria representing pumping yield, total costs, and water-shortage risk were considered. The management model expressed in such a multi-criterion form was based on the finite-element method and a combined embedding/response matrix method. This model was used to generate a discrete representation of a non-dominated solution set. Four MCDM techniques viz., compromise programming, ELECTRE III, multi-attribute utility function, and UTA method representing, respectively, distance-based, outranking, and utility (multiplicative and additive forms) approaches were examined as potential decision-aid tools to select the appropriate management scheme. Comparison of the results showed that these different MCDM techniques lead to a similar subset of recommended solutions.

Gisser and Mercado (1969) developed a theoretical model of integrating an agricultural demand function for water with the hydrologic model of an aquifer in a semi-arid region. Their model combined a single cell hydrologic model with a linear negative sloped demand function for irrigation water. The model enabled both economist and hydrologist to consider several alternative policy interventions to address to the falling water table. The model suggested that no policy was needed if a steady state groundwater level was reached before the allowable minimum level. If the minimum allowable level was reached prior to the steady state level, the model suggested a comparison of the alternative policies such as i) restricting the water pumped to a level that would yield a steady state condition of the minimum allowable level of the water table and ii) artificially recharging replacement flow and investigating the steady state solutions corresponding to it. They concluded that the model could help the policy makers to address to the problem of falling water tables. In addition, the model could also be used to examine the profitability of using the water from surplus area and artificially recharging the aquifer.

A model considering quantity and quality aspects was developed for Netherlands farmers (Hellegers et al., 2001) to study socially optimal agricultural shallow groundwater extraction patterns. The model demonstrated that the current price of groundwater was inefficient and provided fewer incentives for the adoption of modern irrigation technology than did a system that considered the cost of desiccation and groundwater contamination in the price of groundwater. The study showed that including the impact of groundwater extraction on groundwater quality into a resource management model was particularly significant if the recharge of groundwater was large compared to stock size. This impact would be smaller if stock size increased due to the dilution effect. If these externalities were not internalized in the price of groundwater, contamination would be accelerated and quality improvements would be slowed down. This would affect the time path of changes in groundwater stock quality over-time.

Optimization of irrigation water in Mula command area was attempted by Kanade et al. (1989). The irrigation requirement of different crops was computed considering the effective rainfall. The water availability from canal was worked out from the values of discharge. Linear programming technique was used to find out the optimal allocation of land and water as constraint.

Kolberg (1993) applied a theoretical approach to natural resource management. The approach utilized an optimal current period decision rule relating the current period resource stock to the optimal current period application of the relevant decision variable. The single variable functional relation was estimated from data generated with back ward induction utilizing an optimal transition condition that works backward in time from the optimal steady state.

Koundouri and Christou (2000) analyzed the optimal management of an aquifer, with stock-dependent extraction cost and a backstop substitute, facing multi sector linear demands in the Kiti aquifer in Cyprus. The study reported that the presence of a backstop technology diminished the importance of management benefits (3.8%), while its absence made optimal control significantly welfare increasing (409.4%). They attributed this to the near-depletion state of the aquifer under consideration.

McPhee et al., (2004) used a groundwater simulation and optimization technique to construct a decision support system (DSS) for solving a groundwater management problem associated with the Upper San Pedro River Basin, located in southeastern Arizona. In the multi objective optimization problem, environmental objectives were explicitly considered by minimizing the magnitude and extent of drawdown within a pre-specified region. The constraint method was used to derive the tradeoffs among three competing objectives. With a set of efficient solutions (alternatives), fuzzy set theory was applied to rank the alternatives and to assist decision makers in selecting a suitable policy among them, each of which was optimum with regard to its goal and the corresponding consequences. The framework generated information on the best and worst values of the objective functions, given the current state of knowledge of the system and the direction in terms of desirable and attainable management policies.

Martin et al., (1969) used an integrated hydrologic- economic framework to examine the interrelationships of water supply and demand in groundwater basin management for the Pinal County, Arizona. A linear programming framework was used to suggest the cropping patterns that would maximize the net income for the individual farms given the opportunity and constraints faced by them in terms of environment and groundwater management policy. With the constraints of the linear programming specification, water demand model was adjusted to the new conditions and the model was solved for the period't+1'. This cycle of calculations was repeated till the end of planning horizon of 40 years. In addition, the quantity of pumped water demanded under these conditions for each sub-area was determined. The model closely reflected the actual farm adjustments.

Noel et al, (1980) used an optimal control model to determine the socially optimal spatial and temporal allocation of groundwater and surface water among agriculture and urban uses in a representative region of California under several sets of energy costs. They evaluated two policies empirically, pro-rata allocation and taxation as alternatives to account for externalities due to the common pool problems. Their hydrologic-economic framework demonstrated the interaction of several groundwater basins to determine the socially optimal allocation decision. The results illustrated that the several basins making up the aquifer reacted differently to alternative economic and hydrologic parameters. The policy conclusion from this was that the groundwater planning unit should be selected considering economic and hydrologic parameters, particularly the degree of hydrologic interdependence. Secondly, although taxation and pro-rata allocation are the institutional policy instruments for socially optimal allocation of resource, an increase in social value of the resource can be expected as a result of the implementation of the policies.

Selvarajan and Subramaniam (1989) applied a two-stage optimization model involving simulation and dynamic programming approach for the field level optimization and linear programming at the command area level optimization to study water policy options for efficient water management in Amaravathy irrigation system in Tamil Nadu. Optimum water resource management planning suggested that decrease in canal water flow from the maximum to the minimum level increased the groundwater use by 38 to 54 per cent. Judging from the productivity of water under different policy options, the trade-off between surface water saved and net income sacrificed favoured the promotion of conjunctive use of surface and groundwater. The study concluded that maneuverability of groundwater supplementation through appropriate surface water policy measures would have direct policy implication as farmers could be serviced through groundwater recharge and surface water could be diverted to non-well farmers during the period of inadequate surface water flow.

Subbarayan and Singh (1989) used linear programming technique to examine the optimal use of irrigation water resource in the eastern Yamuna canal command in western Uttar Pradesh. The objective function, set in terms of net income to fixed factors, was maximized subject to physical, economic and other infrastructural constraints including groundwater. The findings of the study indicated that sugarcane crop received the maximum quantity of water, followed by wheat and paddy. Of the total water supplies, three-fourth was contributed by surface water and one-fourth, by groundwater.

Worthington et al. (1985) applied dynamic programming to a model of a confined aquifer underlying the Crow Creek Valley in southwestern Montana and found that the difference between the two regimes, optimal control and no-control might not be trivial if the relationship between the average extraction cost and the water table level was not linear and if there existed significant differences in land productivity.

Zachariah and Rollins (1999) developed a dynamic model that jointly optimized over ground water quantity and quality costs and benefits for extractive municipal and non-extractive agricultural users into one inter temporal allocation problem for an aquifer in Southern Ontario. The model predicted extraction levels, production levels and total economic benefits derived from water use and agricultural fertilization under different policy scenarios. The model ranked the different scenarios by benefits from highest to lowest and concluded that in the ideal state, the groundwater extraction rates would be set equal at exactly the amount that would maximize the benefits to the area, and farming would be restricted to a level where the marginal environmental cost of farming would be equal to the marginal environmental benefits.

Utilisation of irrigation water and irrigation use efficiency

Proper utilization of irrigation water commensurate with the water requirement not only enhances the productivity but also makes the resource use sustainable. From both social and private angles, irrigating fields beyond the requisite level is detrimental. While in the public canals, area-linked water tariff and uncertainties of canal supplies explained the sub-optimal water use, in case of private tube well, it is power tariff, earlier in operation, explained the behaviour. A cross-section of studies on utilization of irrigation water use has been reviewed in this section.

Resource use efficiency has been examined by scholars in respect of canal as well as the tube well command areas for different crops and also farm as a unit. Cobb-Douglas type of production function was used and marginal value product (MVF) to opportunity cost (OC) ratios were computed to estimate the resource use efficiency (Mandal et al., 2005; Shaheen and Shiyani, 2005; Datta et al., 2004; Verma, 1995; Senthil Kumar and Alagumani, 2005; Birari et al., 2005; Wadhwani and Bhogal, 2005; Banafar and Thakur, 2005; Tripathi et al., 2005; Kale, et al., 2005; Dhaliwal et al., 2005; Rangappa et al., 2005; Baba and Mann, 2005; Jyothirmai et al., 2005; Srivastava and Singh, 2005; Pant and Nagar, 2005; Dayal et al., 1999). The other scholars used multiple regression analysis (Sinha et al., 2005) and data envelopment analysis (DEA), a non-parametric approach (Kumar et al., 2005; Nasurudeen and Mahesh, 2005). These scholars, by and large, pointed out the inefficiency in input use, including water. The reasons suggested ranged from public extension system (Sagar, 1992), precision farming (Kaur and Sekhon, 2005), to electricity tariff reform (Shaheen and Shiyani, 2005). Details of some works are discussed as under,

Athavale and Yadav (1989) assessed the utilization of irrigation potential of tube wells in Morena district of Madhya Pradesh. The extent of under-utilization was reported to be 53 per cent, largely in summer vegetables, soybean, summer moong, sugar cane and gram crops. They identified electricity supply as one of the reasons for this.

Gupta (1989) examined the extent of under utilization of minor irrigation sources in Narsinghpur district of Madhya Pradesh. The extent of under-utilization on tube well served farms was reported to be 49 per cent. The crops with more than 50 per cent under-utilization included moong and vegetables in summer, paddy, groundnut and jowar in kharif and wheat in rabi season. Sale of irrigation water and un-interrupted as well as timely supply of electricity were suggested for better utilization of the tube wells.

Utilisation and efficacy of irrigation water use from different sources, i.e., canal, electric tube well and diesel pumpset was examined by Kalra (2005) in Western Uttar Pradesh. The study revealed relatively lower productivities of land and water in canal and electric tube well irrigated areas in comparison to diesel engine irrigated areas.

Mitra (1989) in his study in water scarce regions of Maharashtra attempted to understand the utilization of irrigation potential. The extent of utilization in respect of medium irrigation projects was assessed for assured rainfall zone, less assured rainfall zone and scarcity zone. Assessment was done by comparing the area actually irrigated with area proposed to be irrigated and the quantity of water actually released with the water proposed to be released. The results showed that the extent of utilization was low in kharif season in all the zones. The study concluded that the irrigation systems created and designed to provide protective irrigation were also used to fulfill the requirement of high intensity productive irrigation.

Porkharkar (1989) studied the irrigation use efficiency in Mula irrigation command area. The findings of the study revealed that the irrigation water use efficiency was low at farm level. The farmers used the irrigation water inefficiently. Various factors were identified such as the traditional cropping pattern, unleveled land and inefficient management of irrigation system.

Satya Sai (1989) in his study on utilization of irrigation potential of private tube wells in Purnea district of Bihar revealed that the rate of return rises at an increasing rate for every successive increment in utilization. He identified high costs and uncertain diesel supply to be factors affecting the utilization of tube wells. The study concluded that development of extensive groundwater markets and encouraging community tube wells would improve the utilization of irrigation potential.

Sharma (1989) examined the water use efficiency in crops in Indira Gandhi Nagar project, stage II on the basis of productivity of water. The study revealed that among the rabi crops, rape seed, mustard and gram should be given higher weightage in the cropping pattern. Water intensive crops should be taken depending upon conjunctive use of water where possible. The study concluded that deficient irrigation in wheat increased returns per unit of water by diverting the water thus saved to comparatively advantageous crop as rape seed and mustard. Keeping the depth of irrigation equal through physical controls in wheat, rape seed and mustard and gram would increase water use efficiency, help shift cropping pattern in favour of rape seed and mustard and help curb over-irrigation in less water requiring crops.

Thakur and Kumar (1989) did a quantitative assessment of various issues relating to resource productivity and management through profit function approach in Merrut district of Western Uttar Pradesh under different systems of irrigation. The study revealed that improvement in water management on private tube wells farms caused structural break in production relations and shifted the crop production function upwards. The study concluded that the horizontal expansion of irrigation especially through private tube wells would enhance agricultural production and net incomes at a rapid rate.

2.3 Groundwater depletion

The empirical evidence on over-exploitation of groundwater in India is not very clear. While the area statistics of our groundwater potential and its exploitation indicates a high order of exploitation, on the other hand, statistics offered by Central Groundwater Board reveal a bulk of the groundwater potential to be untapped.

Singh and Joshi (1989) examined irrigation economics in Punjab state and reported that the rapid growth of minor irrigation had led to over-extraction of groundwater resulting in emergence of dark zones. The study brought out significant inefficiencies in the allocation of surface water between regions, crop and over time and the need to rationalize the canal and tariff rates consistent with the agricultural productivity.

2.4 Watershed management and water conservation

Arputharaj and Rajayan (1989) evaluated three watersheds of Bavajinagar, Atteyampathy and Vellechikulam in Kerala with respect to water conservation and harvesting scheme. They reported an increase in net income and employment opportunity resulting in improved standard of living.

Temporal variations under pre- and post-watershed management programme were examined by Hanumanthaiah and Nataraj (1989) in Chinnatekur watershed of Kurnool district of Andhra Pradesh. The study revealed a radical change in land use pattern between pre- and post-watershed period. The dry land area declined, while dry-cum-wet area increased during the period. The cropping pattern showed considerable variation, an increase in mixed cropping and introduction of new crops like red gram. Per capita income as well as the production of pulses and oilseeds increased tremendously. The programme provided employment opportunities by changing land use and cropping pattern.

Kulkarni et al. (1989) did a study in Asundinala watershed in Dharwar district of Karnataka to examine the watershed management impact on productivity, cropping intensity and profitability. They divided the study area into three regions, watershed area completely treated with soil and water conservation measures, watershed area only partially treated and area outside the watershed for the impact study. Their study revealed that the productivity and profitability of the selected crop as well as the cropping intensity were much higher in watershed area completely treated with soil and water conservation measures as compared to the other two areas.

Mahandule et al. (1989) did an economic analysis of watershed management in drought-prone area of western Maharashtra. The findings of the study revealed that the proportion of irrigated area and cropping intensity increased as a result of the implementation of the watershed management programme. The productivities of resources showed an improvement indicating thereby the importance of the watershed management programme for increased agricultural production through resource conservation in the drought-prone areas.

Pagire (1989) examined the impact of watershed development programme on cropping pattern, crop productivity and agricultural income at Kolhewadi village in Ahmednagar district of Maharashtra. He reported an increase in the area under the kharif and rabi crops and diversification in the cropping pattern during the period. This resulted in an increase in agricultural income from both kharif and rabi crops.

Impact study by Prasad et al. (1989) in Rendhar watershed management project in Jalaun district of Uttar Pradesh reported a shift in the cropping pattern, increase in the productivity of crops and cropping intensity. The productivity of different crops increased by three to five times as compared to the base year. The higher productivity resulted in higher returns as a result of the watershed management programme.

Optimal control theory

The theory of optimal control has been applied to macro economic problems such as the choice of the best policy to regulate and stabilize the economy. These policy problems include how and when taxes should be raised or lowered, at what rate money supply should grow, how fast the apex bank should change credit conditions etc.

In the optimal control literature scholars have demonstrated the potential application of optimal control theory to economic stabilizations (Chow, 1966; Sengupta, 1970; Theil, 1964). Similarly, some scholars demonstrated its application to examine long terms economic growth and development (Dobell and Ho, 1967; Fox et al., 1966; Kendrick and Taylor, 1969, 1970; Shell, 1967).

Pindyck (1972) used the optimal control problem to study the choice of policy to best regulate and stabilize the economy. In his study the optimal control problem was defined as a dual discrete-time tracking problem where nominal state and nominal policy trajectories were tracked for a linear time invariant system with a quadratic cost functional. Philips (1954) through tracking problem study showed that in a multiplier-accelerator macro economic model, application of certain stabilization policies might result into fluctuations. Collings et al., (1996) used the information-state approach to obtain solutions to risk-sensitive quadratic control problems. They considered the case of tracking a desired trajectory. Results were presented for linear discrete-time models with Gaussian noise, and also for finite-discrete state, discrete-time hidden Markov models with continuous-range observations. Using such methods the tracking solution was obtained without appealing to a certainty equivalence principle. The results demonstrated the link to standard linear quadratic Gaussian control and achieving zero steady state error with risk-sensitive control policies. Kendrick, (1979, 1982) used control technique following the linear tracking approach to a small macro economic model of the U. S. economy. He used both monetary and fiscal policy variables to study probing and active learning in tracking the macro economic parameters of the economy. Coomes (1988) used stochastic control method to solve the agricultural policy problem. He constructed a small model of corn market with two state variables (acreage and price) and two USDA controls (acreage set aside requirements and acreage diversion payment). Martens and Pindyck (1975) used quadratic linear optimal control to long term multi sectoral planning in Tunisia.

2.5 Missing link and contribution of the study

The issues of water resources management encompass multi-faceted themes. These range from macro scale such as inter-basin water management to micro scale management such as management of water at farm level. While both have their own merits, the policy intervention at farm level with catchment as basic unit would be an interesting initial step to manage water, extended to basin level subsequently. Most of these issues addressed by the scholars working in the field of water resources management pertain to hydro-economic modeling. These complex models mostly examine the groundwater management at basin scale with macro policy interventions. However, the impact of these interventions at farm level would not be direct and would occur with a time lag. Moreover, as suggested by some scholars the response of economic parameters would vary dramatically for some basins with in an aquifer (Noel et al., 1980). At the catchment level, such interventions would require an understanding of the groundwater extraction pattern in the existing irrigation scenario. Further, complex systems analysis and optimization techniques such as ground-water management models, inverse solution techniques for parameter identification, and optimal experimental design methods have been used for the planning and management of a ground-water system. The techniques used in the optimization of ground-water management viz., linear programming, mixed-integer and quadratic programming, differential dynamic programming, nonlinear programming, and simulation are complex and warrant huge and accurate data sets. Because of data limitation in both quantity and quality, most of the techniques are not properly applied, in the Indian context.

Further, in order to make a more confident assessment of local situations, data sets need to be developed and analyzed on behaviour of groundwater table in terms of volume of water extracted with respect to the cropping systems practiced in varying rainfall situations in semi arid climate, area irrigated and the trend of groundwater extraction from wells serving different crops and cropping system in a geo-hydrologic setting. Management of a natural resource like groundwater makes practical sense when discussed in the context of a catchment / watershed. The data on groundwater extraction and use in agricultural production is scantly available at watershed scale. A systematic data base on the extraction scenario over the crop growth stages for the major cropping systems in the watershed can help plan the optimal use of water in general and groundwater in particular for resource sustainability. It, therefore, becomes imperative to examine the groundwater extraction from wells, depth of water and, thus, the energy used in groundwater extraction to examine groundwater productivity in particular and these issues in general. This is more so for the areas served only by groundwater. Evidences from hard rock areas of South India suggest that lowering of groundwater level as witnessed in terms of increased number as well as depth of wells do not match the reduction in the total areas served by the wells. Tendency to shift crops and cropping systems with the availability of water, on the part of farmers, have been ascribed as one of the reasons by some scholars. This, therefore, calls for looking into the issues of groundwater extraction and the changing crop pattern in detail in a given hydrological setting. While this may define the phenomena in some particular case, this can not be generalized for others. Trend of aquifer response to agricultural activities undertaken over the concerned geographical area vary depending upon the several climatic, soil and geographic properties of the underground strata. For a catchment with given properties and geographic profile of soil, climatic factors particularly the rainfall does have a profound influence on the behavior of the aquifer. Study of the relationship between groundwater extraction and crops in varying rainfall scenarios at farmers' field would definitely add to the understanding of the actual phenomena based on ground realities rather than building the virtual relationships as done in few of the groundwater models used by the scholars in the field of groundwater resource management.

Studies on input use efficiency in irrigated agriculture focused on macro policy aspects of tariff and extension system of the state. Water use and its management at farm level with implications on cropping systems practiced, particularly in respect of groundwater, received only little attention. This issue needs a fresh thinking as the said supply side policy interventions have their own fate of partial success. The present study attempts to look at the demand side management of the resource and examines the water use and its productivity in a changing rainfall scenario in a catchment area.

The state of groundwater affairs can be better appreciated and the resource, better improved if there were systematic and continuous monitoring of the average yield per well, the area irrigated per well and the cropping intensity and crop pattern in well irrigated areas (Vaidyanathan, 1996). At catchment scale, these parameters and their intricacies not only affect the groundwater recharge and discharge but also the activities in the neighbouring catchment. While a study of such a complex relationship would require huge cost in terms of time and man power, magnitude of the complexity and the behavioural relationship can be understood in its simplest form by monitoring and studying the groundwater extraction and the copping system served by wells in a catchment.

Contribution of the study

The present study attempts to examine the groundwater extraction by wells and the cropping systems irrigated in its command in a semi-arid watershed in India under varying rainfall scenario with the real time field based data collected over the years. An attempt is made to fill the gap in knowledge about the issues discussed, by understanding the relationships between volume of groundwater extraction, cropping systems in the command of the wells, depth to water table in wells etc. Understanding about the crop water productivities for the significant crops and cropping systems in the watershed is built up to know the water use efficiency in general and groundwater use efficiency in particular.

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