GROUNDWATER EXTRACTION AND CROPPING SYSTEM

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4.1 Overview

Reliable water supplies, particularly those from groundwater, are the lead inputs for increasing yields, reducing agricultural risk and stabilizing farm incomes. While water availability and reliability are linked closely to food security, "the equation linking water to food security is partial and the links are neither linear nor transparent. The full equation is a function of the interaction between water access, production economics and the wider network of entitlements that water users and others have within society. It cannot be assumed that a one-to-one relationship exists between access to reliable water supplies for irrigated agriculture and food security" (Moench et al., 2003). Yet the socio-economics of intensive groundwater use in agriculture is important to understand because of its critical links with the livelihoods and food security of some 1.2-1.5 billion rural households in some of the poorest regions of Asia and Africa. In small-holder farming systems in South Asia, agricultural groundwater use generates relatively little wealth and has low productivity, but supports vast numbers of poor rural households. In the subsistence agriculture of the region, however, the rapid expansion of groundwater irrigation has had profoundly positive region-wide impacts on land productivity, total food production and the livelihoods of small-holders.

Irrigated agriculture now contributes almost 40 percent of world food production from 17 percent of cultivated land (United Nations, 1997). About 70% of the world groundwater withdrawals are used for irrigation purposes. In India, the groundwater-irrigated area accounts for about 50 percent of the total irrigated area. There are over 20 million private wells, in addition to the government tube wells and up to 80 percent of the country's total agricultural production may, in one form or another, be dependent on groundwater (Dains and Pawar, 1987). In Gujarat, decline in the groundwater table increased from 1 m yr^{-1} in 1970 to 2–8 m yr^{-1} in 1997 (Central Ground Water Board, 1998). About nineteen districts have experienced this fall in water table (Center for Water Policy, 2005). The overexploitation of groundwater is driven mostly by irrigation needs. More than 90% of the total cultivated area in north Gujarat is being irrigated by groundwater sources. Groundwater development has been over 100% in Banas, Saraswati, Rupen and Sabarmati basins and 93.55% in Rel basin. Groundwater balance in this region is negative. As many as 52 talukas in the districts of Banaskantha[6], Mehesana[11], Sabarkantha[2], Gandhinagar[1], Ahmedabad[3], Kheda[3], Vadodara[3], Bharuch[2], Amreli[2], Jamnagar[1], Junagadh[8], Rajkot[2], Surendranagr[2] and Kutch[6] are in the over exploited category where the withdrawal is more than the recharge. This is due to a market oriented shift in the cropping pattern from food crops to commercial water-intensive crops, which has escalated the demand for groundwater sharply.

The technological advancement in recent past has lead to a shift from traditional dug wells to dug-cum-bore wells. But the capacity of dug-cum-bore-wells to meet increased demand for groundwater has reduced as a result of higher exploitation and reduced water depth in the wells. This has forced farmers to venture further in exploring groundwater through deeper fractures of the aquifer by means of deeper surface bore-wells. The access to institutional finance has helped in a rapid spurt in the wells. Further, with the introduction of modern extraction mechanisms, the groundwater extraction scenario altered drastically. The subsidized electricity to the agricultural pump-sets 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. In the hard rock areas of Peninsular India, the share of less water-intensive food crops dropped drastically and high value water-intensive crops like vegetables, flowers, fruit crops, cereals, sugarcane gained in acerage, leading to exploitation of groundwater. Arresting this trend is the need of the hour. The related issues with socio-economic-institutional-legal aspects, thus, include changing the cropping pattern to match irrigation water requirement with the recharge rate, introducing irrigation technologies that would increase water use efficiency or reduce the demand for water, introducing economic instruments such as pricing of electricity, water or increasing the interest rate for well loans.

4.2 STATEMENT OF PROBLEM

Groundwater will continue to be used intensively, as farmers adopt groundwater irrigation due to apparent reliability of storage offered by mechanized drilling and pumping, and flexibility of groundwater exploitation. The green revolution, also called as tube well revolution by Repetto, 1994, which hinged around high value crops with high water budgets and investment on bore wells brought the associated problems of falling water tables in certain parts of the Asian region, particularly the Paddy (*Oryza sativa*) – Wheat (*Triticum spp.*) belt of North-western India. While much of this debate 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. One tenth of the semi-arid tropics of the world is located in India, occupying almost 1.23×10^6 km^2 (37% of the total geographical area) (Datta, 2005). The region's economy is mostly based on agricultural activities, the largest abstractor of groundwater, and is generally the highest user of water by volume with changes in cropping systems to raise cash crops.

The research on groundwater use in the socioeconomic context is relatively small, and, hence, the technical knowledge of the aquifer systems presented in the literature is of relatively little use for management purposes (Datta, 2005). While under pricing of groundwater (through subsidized power) has resulted in social implications like inter-personal spatial inequalities in access to the resource, and inter-generational inequity implied by the depleting reserves (Mehra et al., 2000), the practice of sale of water, either in cash or on crop sharing basis has encouraged rich farmers in constructing deep tube wells and over pumping the groundwater. Aquifer systems are known imperfectly, there are no clear solutions of continuity, and responses are highly nonlinear in terms of geological heterogeneity (Datta, 2005). For practical management practices, therefore, it is important to examine people's adaptive strategies, when they face groundwater scarcity problems and the policy implications, like drought relief, climate-change response, investment directions, institutional forms, etc. 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.

Approximately two-fifths of India's agricultural output comes from areas irrigated with groundwater. Because agriculture and allied activities contribute roughly 30 percent of India's GDP, with crops accounting for three-fourths of this, the contribution of groundwater (with a package of associated inputs) to India's GDP is about 9 percent. With its nationwide policies governing the support price for agricultural crops, national level policies could be tailored to reflect regional water availability differences in the country. Thus, there is scope for savings in agricultural water demand by encouraging production of medium water intensive and less water intensive crops in areas with different comparative advantages. In this context, detailed study of the cropping systems to reflect their water use in the field, in general and groundwater extraction pattern, in particular, makes sense for eventual policy intervention to control the groundwater exploitation in agriculture sector. Yet, the systematic information on crop wise yields and crop pattern and cropping system irrigated by groundwater exploitation is sparsely available. This necessitates recourse to micro level data gathered through surveys (Dhawan, 1986).

4.3 REVIEW OF PAST WORKS

Deepak et al. (2005) studied groundwater users in eastern dry zone of Karnataka to compare the water use efficiency among different categories of water users, viz. well owners who do not sell water, well owners who sell water either for agricultural or non-agricultural use and water buyers (both agricultural and nonagricultural). They reported that cropping pattern varied between categories, with both the sellers and buyers preferring low water intensive mulberry crop, while the self-user's category grew more water intensive crops. The study concluded that end-use pricing was a key in shaping marginal productivity of water.

Study conducted by Deore et al. (2005) on sustainability of groundwater utilization in Thane district of the Konkan region in Maharashtra examined the impact of groundwater irrigation on crop production and returns on water use efficiency. The study analyzed the cost of irrigation by types of wells, dug well, bore well and dug-cum-bore well and reported the extent of increase in water use efficiency to be in the range of 102 – 194 per cent. The per well quantity of water used for irrigation was found to be higher with the traditional method of irrigation compared to the modern method.

Dhawan (1986) examined cropping pattern under well irrigation with special reference to the Maharashtra state. Specifically, he examined the issue of sugarcane versus field crops. The study observed that dug wells were overwhelmingly used for the production of food crops. Food crops had somewhat higher proportion in the irrigated crop pattern than in the dry crop pattern without well irrigation. He reported that garden crops (fruits, vegetables, sugarcane etc), which were practically absent from the dry crop pattern, came to occupy an important place once access to well irrigation was established.

The study concluded that in the wake of well irrigation, farmers attempted to reduce irrigated area under main rain-fed crops and enlarged area under other crops which can normally not be grown without irrigation.

Kumar et al., (1989) conducted a study on impact of water management on crop pattern and resource use in Maili watershed in Kandi tract of Punjab. An earthfill dam was constructed in the watershed by the Irrigation Department of the Punjab Government for harvesting and utilization of run-off. They reported a shift in the crop pattern in favour of high yielding varieties of wheat and commercial crops such as sugarcane, oilseeds, vegetables and pulses as a result of water management programme.

Mondal (2005) studied tube well irrigation in terms of water use efficiency between owners and non-owning purchasers of water in West Bengal. He examined the crop pattern and quantum of irrigation used for the crops in the two category of cultivators. He reported that kharif and summer paddy dominated the crop pattern of both the type of cultivators. He further observed that while the tube well owners tended to over irrigate, the non-owners achieved the efficiency in irrigation by some adjustment and alteration in frequency of watering. The study recommended adoption of a suitable crop pattern with high, medium and low water-intensive crops to avoid the problems of lowering groundwater table and bringing an economy in water use.

Ram et al., (1989) studied the common property usages of groundwater using household level data. They reported that the cropping pattern under irrigated conditions was in favour of crops yielding higher private returns but consuming relatively more water. Water use efficiency was at a discount because the groundwater use practically was free of cost as the power tariffs were linked to horse power of engine and not to power consumed or water drawn. The study further reported that the nature of groundwater and the least cost structure of groundwater use had apparently promoted a cropping pattern that was not in the larger interest of groundwater resource nor was it on socially desirable lines because of over-drawal of groundwater.

Rao (2005) in his study on resource efficiency of groundwater potential by tube well irrigation in Rajsamand district of Rajasthan examined the effect on cropping pattern, crop production and elasticity of factor inputs. He observed that the tube well owners sold water to neighboring ancillary industries and due to water scarcity the cropping pattern has been changed by the farmers. The study concluded that the value of the produce by cropping pattern was negative for all types of tube wells under study. .

Saini et al., (1989) examined the locational factors of right bank of Giri Canal Irrigation Project, Majra in Paonta block of Sirmaur district of Himachal Pradesh on cropping patterns among other aspects. The canal was divided into three reaches, head, middle and tail and forty farmers each were randomly surveyed. The study revealed that after the launching of the irrigation system, the farmers of head reach, due to adequate availability of water, allocated a considerable proportion of area to more water intensive high yielding varieties of rice, maize and wheat. In contrast, the farmers in tail reach allocated a larger proportion of the total cropped area to local varieties of these crops because of in adequacy and uncertainty of canal water.

Sarkar et al. (2005) analysed the sustainability status of rice – wheat cropping system under different irrigation systems in Punjab. The study examined different systems, viz., canal irrigated, new tube well system shifted from canal irrigation, over-exploited specializing tube well irrigation system and over-exploited diversifying tube-well irrigation system. The wheat-paddy cropping system was examined for productivity, stability and water use efficiency in terms of rainfall and irrigation. The study concluded that over-exploited groundwater dependent agriculture need diversification to improve in terms of sustainability with positive externality impact on the residual wheat-paddy cropped area.

Shaheen et al. (2005) studied water use efficiency and externality in the groundwater exploited and energy subsidized regime of north Gujarat. They examined the efficiency of groundwater use by comparing economic optimum groundwater use with actual groundwater use. The study estimated groundwater extraction by the type of ownership of wells and reported about the inadequacy of groundwater for family well group farmers, which was most prominent in the Banaskantha district of North Gujarat.

Sharma (1989) conducted a study on water use efficiency in crops and option of deficient irrigation in Indira Gandhi Nahar project, stage II. The study of different crops revealed that among rabi crops, rape seed and mustard and gram should have higher weightage in cropping pattern. Among kharif crops, grass enjoyed a comparative advantage in yield over groundnut/ cotton. The study reported that deficient irrigation in crops like wheat increased returns per unit of water diverting the water thus saved to comparatively advantageous crop like rape seed and mustard. The study recommended that keeping the depth of irrigation equal through physical control in wheat, gram, and rape seed and mustard will increase water use efficiency, help shift cropping pattern in favour of rape seed and mustard and gram and curb over-irrigation in less water requiring crops.

Sharma and Acharya (1989) examined the cropping pattern with respect to the distribution of canal water between head and tail-end farmers in Guda Irrigation Project area in Bundi district of Rajasthan. Optimal cropping plans were developed using linear programming technique. The study reported divergence between existing and optimal cropping patterns with respect to the canal water distribution.

Sonnad et al., (1989) studied the cropping pattern and farm income in relation to conjunctive use of water in Bijapur district of Karnataka using farm level data. The crop enterprises were evaluated by adopting the farm management cost concepts. The study reported a shifted in cropping pattern in favour of commercial crops with the advent of conjunctive use of water.

Umesh et al. (2005) in their study on efficiency of irrigated agriculture across different sources of irrigation in Southern trasition zone of Karnataka analysed the cropping pattern and reported that in groundwater irrigated area, ragi, arecanut and pulses dominated the cropping pattern. The study further concluded that the net income and return per rupee of investment was lower on groundwater-irrigated farms because of higher fixed costs incurred toward irrigation wells.

Most of the studies examined the groundwater exploitation issues in terms of production, water use efficiency and production costs. A few studies such as Dhawan (1986), Mondal (2005) and Umesh et al. (2005) examined the cropping system in different irrigation systems. The relationship of groundwater extraction with the cropping systems in the context of a geo-hydrological unit was weakly established for semi-arid tropics. The uncertain and irregular variability in rain fall pattern makes the region vulnerable to the only source of water harvesting, thereby, making groundwater a dwindling source. Despite technological advancement on supply side of groundwater management, the demand management is still the crucial dimension in the debate of sustainable groundwater management. In this context, the relationships of groundwater extraction with the prevailing cropping systems need to be established for a particular geo-hydrological setting to understand the linkage. This would make policy intervention relevant and justified.

4.4 HYPOTHESIS

It has been well documented that farmers tend to alter their dry crop pattern once they have access to irrigation and the degree of crop diversification is governed by availability of well water and their marked preference to crop and/or a group of crops (Dhawan, 1986). Considering these facts, and also the observation that the crops and their combination adopted on farm depend on reliability of the source of irrigation, it is imperative to examine the relationship between the cropping system practiced and water, particularly with reference to the groundwater extraction in the semi-arid tropics, where this relationship is further susceptible to vagaries of the climate. Establishing this relationship and understanding the change in the behaviour of farmers in respect of adopting crop system could help device interventions to manage demand for groundwater exploitation. The present study attempts to understand these intricacies with the observations that, (1) with increased water availability, farmers' tend to put area under crops which can not be grown without the aid of irrigation; (2) there exists relationship between cropping systems practiced and the groundwater extraction and (3) higher groundwater availability results in more groundwater extraction by the cropping systems adopted

4.5 METHODOLOGY

4.5.1 DATA COLLECTION

Data used in the study were collected both from primary and secondary sources. The primary data on agricultural water use were collected through field surveys for the three seasons from all the tube well owning farms irrigating the crops from groundwater in the watershed. The socio-economic data on groundwater use pertained to the agricultural years 2003-04, 2004-05 and 2005-06. The agricultural year was defined as period between June to May comprising of three seasons, namely *kharif* (June to September), *rabi* (October to January) and summer (February to April).

4.5.1.1 Crop input and output

The data was collected on crop-wise input details such as seeds, fertilizers, chemicals, human, bullock and machine use, yield of crops, and groundwater pumping details, such as schedule of irrigations (numbers, date of water application, tube well motor running hours during different irrigations). A detailed questionnaire was prepared after pre testing and tube well owners were personally interviewed.

4.5.1.2 Groundwater extraction

The details on groundwater extraction included capacity of electric motor, depth of motor placement, volume of groundwater extracted per unit of time. In absence of direct measuring device for groundwater pumping, information was collected on time (minutes) taken by a tube well to fill a container of 100 litre capacity. This gave an estimate of the volume of groundwater discharged from a well and coupled with the information on duration of crop wise irrigation on individual farms, an estimate of groundwater extracted in the command of each functioning well was computed. The collected information was mapped for the area under study to understand the water withdrawal scenarios.

4.5.1.3 Depth to water table

This information was collected from the secondary source. About 35 tc 40 wells in the watershed are regularly under monitoring at the Central Soil & Water Conservation Research & Training Institute, Research center, Vasad for weekly and fortnightly fluctuation in the water level in the wells throughout the year. During the agricultural year average depth to water table was computed from the available information and mapped with the groundwater extracted as well as the crops and cropping system practiced in the command area of the particular well to examine the relationship between water table and cropping system.

4.5.1.4 Well details

Primary information on dug wells and bore wells was collected on depth of well, depth of motor placement, year of well digging, irrigation event-wise motor running hours and capital investment on well digging, motor and water conveyance system to field, operation and maintenance of well and the year of well failure in case of wells not in present operation.

4.5.2 Technique used

The existing data set comprised of the crop and cropping systems as different groups and were hypothesized to be statistically different in terms of a single grouping variable, groundwater extraction. The hypothesis framed in respect of relationship between cropping systems and groundwater extraction was tested using Univariate Generalized Linear Model technique, though there are several statistical procedures to examine the relationship. The Independent-Samples T Test procedure uses a grouping variable with two values to separate the cases into two groups. For a single value-grouping variable, this procedure will split the population into two groups, above and below the value of the variable. One-Way ANOVA procedure can be used for the purpose and considers factor variable values to be integers, however, it does not provide for test between individual mean group differences. The objective of present study included identifying the cropping systems significantly differing in mean groundwater extraction. Therefore, the Univariate Generalized Linear Model procedure best fitted the data set for the purpose of the present analysis. Further, the null hypothesis about the relationship between cropping systems and the groundwater extraction could be tested taking groundwater extraction as dependent variable and the cropping systems as independent variable. To test the hypothesis about farmers' inclination to put more area under water requiring crop with increased water availability, the above relationship was examined under different rainfall and groundwater availability scenarios.

4.5.2.1 Univariate GLM Procedure

Generalized Linear Model (GLM) univariate procedure was used using SPSS 10.0.1 standard version to test the null hypotheses and test the significance of difference in mean groundwater extracted. The GLM Univariate procedure provides regression analysis and analysis of variance for one dependent variable by one or more factors and variables. The factor variables divide the population into groups. The procedure tests the null hypotheses about the effects of other variables on the means of various groupings of a single dependent variable. The procedure also examines the interactions between factors and the effects of individual factors, some of which might be random. For regression analysis, the independent (predictor) variables are specified as covariates. One of the advantages of this procedure is that in addition to testing hypotheses, it also estimates the parameters of the effect of independent variable on the dependent variable. This procedure also evaluates the significance of differences in group means assuming data to be a random sample from a normal population. Although the analysis assumes the data to be symmetric, this is robust even to departures from normality. The homogeneity of variances tests and spread-versus-level plots are used to check the data symmetry. The data on dependent variable is taken as quantitative and the factors as categorical for the purpose of analysis.

4.5.2.1.1 Model specification

For the purpose of GLM analysis a full factor model was chosen. This contains all factor main effects, all covariate main effects and factor-by-factor interactions. Type III sum-of-squares method was used as this is appropriate for balanced models with no missing cells. This method calculates the sum of squares of an effect in the design adjusted for any other effects that do not contain it and orthogonal to any effects, if any, that contain it.

4.5.2.1.2 Univariate GLM Contrast

Contrasts were used to test for the differences among the levels of a factor. Mean of each level was compared with the mean of all of the levels (grand mean) using deviation type contrast. Simple deviation type contrast was chosen to test the mean of each level to the mean of a specified level, with last category taken as the referenced specified level.

4.5.2.1.3 GLM Post Hoc test

After establishing the existence of the differences among the means, post hoc range test and pair-wise multiple comparisons was done to determine the pair of means which differed. The pairs of means were tested using Bonferroni significant difference test.

The analysis produced marginal means estimate adjusted for the covariates, if any. The main effect comparison provided uncorrected pair-wise comparisons among estimated marginal means for any main effect in the model, for both between and within subject factors. The estimates of the effect size produced partial eta-squared values for each effect and parameter estimate. The eta-squared statistics describe the proportion of total variability attributable to a factor. Levene test of the homogeneity of variance was used to test homogeneity in data set. This homogeneity of variance was examined for each dependent variable across all level combinations of the between-subjects factors for between subjects factors only.

4.6 RESULTS

4.6.1 Crops grown and groundwater extraction

Crop wise details of groundwater extraction in the watershed is given in tables 4.1 through 4.3. Cotton is the dominant crop in terms of the cropped area irrigated by groundwater in the watershed. This is followed by fennel, castor and wheat. The inter year variation notwithstanding, half of the total irrigated area under tube well is occupied by this crop. This being a water intensive crop, acccunts for the maximum groundwater extraction. Prior to the year 2003-04, the watershed faced consecutive drought for four years. The year 2003-04 received a normal rainfall. Coupled with the water harvesting structures executed under the Integrated Wasteland Development project in the watershed, the groundwater availability increased over the years. In comparison to the previous year, year 2004-05 realized more groundwater recharge and therefore, not only area under irrigated crops increased but also the number of irrigations.

The total groundwater extracted increased from 235,588 m^3 in the year 2003-04 to 491,757 m^3 in 2004-05 (Tables 4.1 and 4.2). The share of cotton in total water extraction did not change much, from 89.9 per cent in 2003-04 to 88.7 per cent in 2004-05, though area under crop drastically changed. Farmers preferred to put more area and apply more groundwater to other crops also like castor, fennel and cumin. The number of irrigations given to these crops slightly increased. The year 2005-06 was an exceptionally high rain fall year, the groundwater extraction increased by eight times as compared to the previous year. The tendency of farmers to apply higher irrigation than that in the normal year was clearly observed from Table 4.3. The number of irrigations given to different crops roughly doubled. Another visible trend was observed in terms of change in cropped area under fennel and castor. The fennel area increased by more than double (37.0 acre in 2004-05 to 104.0 acre in 2005-06), the same under wheat increased by six times (6.2 acre in 2003-04 to 37.5 acre in 2004-05). Another interesting feature of this trend was three times increase in the area under summer pearl millet (15.0 acre to 46.7 acre). The drastic increase in area under summer cropping was not observed prior to the increased availability of the groundwater in the watershed. These observations about the diversification in crop systems in the event of more groundwater availability supported the findings of Dhawan (1986) in Maharashtra.

4.6.2 Variation in annual groundwater extraction by cropping systems

The relationship between the volume of groundwater extraction and cropping systems practiced in the tube well command in the watershed was analyzed to know the existence of relationship, if any, between the two and also the significance of the relationship to draw the conclusive evidence. Total annual volume of groundwater extracted from an individual well and the crops and cropping system irrigated by that particular well in its command was analyzed over the entire watershed.

Prior to analysis, Levene's test of equality of error variances was performed on the data (Table 4.4) to test whether the error variance of groundwater extraction is equal across the groups. The test confirmed that variances were not homogeneous across the groups. However, the data set was small, violation of homogeneity assumption did not affect the results seriously and the analysis was performed using the technique. The Generalized Linear Model Univariate test was done on the two sets of data, crop system served by tube well and the groundwater extracted during the year.

It was revealed (Table 4.5) that variation in annual groundwater extraction across the cropping systems irrigated by the tube wells was significant over the period studied, individually as well as taken together, i.e. pooled analysis. The fitted model explained the variation in groundwater extraction from 68 per cent during 2003-04 to 93 per cent during 2005-06, for the whole period the variation being 87 per cent.

Further, the differences among the levels of groundwater use by cropping systems were tested using GLM univariate contrast test. This test is based on the linearly independent pair wise comparisons among the estimated marginal means. The contrast test (Table 4.6) clearly brought out the significance of the differences in the annual groundwater extracted by the various cropping systems practiced in the watershed.

This indicated that not only the annual groundwater extraction and the cropping systems practiced in the watershed are significantly related but also, in general the annual groundwater extractions estimated from the model are significantly different among the cropping systems.

4.6.3 Mean groundwater extraction by different cropping systems in the watershed

The mean level of extraction of groundwater by different cropping systems was examined to assess the variation in the extraction levels of the cropping systems. Farmers practice different combinations of crops in a year in the tube well command. Prominent crop systems in terms of groundwater extraction were identified to know which systems withdrew significantly different mean volume of groundwater than mean annual extraction in the watershed.

Farmers practiced different cropping systems in their tube well command depending upon the water availability in the well and capacity to extract groundwater. On an average, during the period 2003-04 through 2005-06, 1666.5 m^3acre^{-1} groundwater was extracted (Table 4.7). The mean annual groundwater extraction level varied from 18.60 m^3acre^{-1} in cotton + maize inter crop to 13440 m^3acre^{-1} in Cotton-castor-fennel-cumin-summer pearl millet cropping systems. Among the cropping systems, while fennel mono cropping (910.3 m^3acre^{-1}), cotton mono cropping (1354 m^3acre^{-1}), and paddy (188 m^3acre^{-1}) mono cropping systems had significantly less groundwater extraction, the cotton based systems had significantly more than mean annual groundwater extraction in the watershed. Among the different cropping systems followed, the maximum variance in groundwater extraction was exhibited by cotton-castor-fennel system, followed by cotton-castor-fennel-cumin-summer pearl millet and cotton-castor-fennel-summer pearl millet cropping system.

4.6.4 Major cropping systems affecting groundwater extraction in different rainfall and groundwater extraction scenarios

In contrast to the pooled data, the analysis for the individual years reflected an annual trend because of differential pattern of rainfall, groundwater recharge and the groundwater extraction. The mean annual extraction showed an increasing trend over the period 2003-04 through 2005-06. The rainfall received and assured groundwater availability during these years explained this trend. With the availability of more groundwater, farmers not only put more land under different cropping systems but also extracted more groundwater, particularly during 2005-06 when the total rainfall was roughly three times the average rainfall of the region.

During the year 2003-04, the mean annual groundwater extraction in cotton mono cropping, cotton with castor, fennel, cumin and sunflower based cropping systems were significantly different than the mean groundwater extraction in the watershed (Table 4.8). While pure cotton and double cropping of cotton with castor, sunflower, fennel and cumin crops were the major cropping systems in terms of significantly higher groundwater extraction than the mean groundwater extraction level, the other mono crop like pure fennel had significantly less than mean groundwater extraction. In addition, sun flower with fennel and drum stick also extracted higher groundwater than the mean watershed extraction level but strength of the relationship was poor (Eta squared 0.23, 0.24). On the contrary, fennel mono cropping system extracted significantly less groundwater than the watershed mean level. The groundwater extraction level of other mono crops did not turn out to be significant. In terms of proportion of variance in groundwater extraction, however, cotton mono cropping system explained the maximum variance (0.90), followed by cotton-fennel (0.70), cotton-castor (0.65) and Cotton-castor-cumin (0.47).

During 2004-05, pure cotton and cotton based cropping systems again had significantly higher groundwater extraction than the mean annual groundwater extraction in the watershed (Table 4.9). The interesting trend was many fold increase in the number of crops in cotton based cropping system. While the castor mono cropping system extracted significantly less groundwater (570 m^3 $acre^{-1}$) than the mean annual groundwater extraction, the other mono cropping systems were not significantly different than the mean groundwater extraction. The highest mean annual groundwater extraction (5290 m3 $acre^{-1}$) was done by cotton, drum stick and had the maximum variance explained among the cropping systems followed in the watershed.

Similar trend was observed during 2005-06 also (Table 4.10), where the predominant cotton based cropping system reported much higher number of crops than in previous years. Fennel based systems had significantly less than mean groundwater extraction in the watershed. The mean annual groundwater extracted in the watershed during this year worked out to be 3493 m^3/acre, much higher than that in previous years. While a majority of the cotton based cropping systems depicted significantly higher groundwater extraction trend, some crop systems like cumin-summer sorghum, cotton-cumin, fennel-summer pearl millet, fennel-cumin and cotton mono cropping systems had significantly less groundwater extraction than the mean watershed level.

Among the major cropping systems, cotton-castor-fennel group explained the maximum variance in the groundwater extraction among the farms growing this system in the tube well command in the watershed. This was followed by cotton-castor-fennel-cumin-summer pearl millet and cotton-castor-fennel-summer pearl millet.

4.6.5 Mean annual groundwater extraction: Comparison among cropping systems

The major cropping systems with significant groundwater extractions were compared among themselves to examine the significance of the mean difference. Though cotton mono cropping and cotton based cropping systems are the major cropping systems in terms of groundwater extraction, some of them also turned out to be significantly different from each other (Table 4.11).

Among the cotton based cropping systems, the difference in the mean extraction levels of majority of the systems, however, did not turn out to be significant. During the year 2003-04, the groundwater extraction by cotton mono cropping was significantly different from cotton-castor and cotton + maize inter crop only. The groundwater extraction by all other cotton based inter cropping systems were statistically same at 5 per cent significance level.

On the contrary, it was significantly higher than most of the other cropping systems such as paddy, castor, fennel, sun flower and summer pearl millet mono cropping systems. Similarly, during 2004-05 also, cotton mono cropping and cotton-castor cropping system had significantly different groundwater extraction than cumin, castor, summer pearl millet mono crop and wheat-paddy cropping system . However, this trend was not observed during 2005-06. Whereas, cotton mono crop and cotton-fennel had significant difference in terms of mean annual groundwater extracted, cotton-fennel was also significantly different from fennel mono crop. All other cropping systems were statistically at par in terms of groundwater extraction level. In other words, cropping systems other than cotton based also extracted equal high volume of groundwater during the year of high groundwater availability. This could be explained in terms of high groundwater recharge, as the year received unusually high amount of rainfall, which raised the groundwater level in the aquifer. This prompted the farmers to apply more irrigations than that in the previous years.

It can be inferred from the analysis that during the period of normal rain fall and groundwater recharge, farmers exercised caution in the extraction and use of groundwater to fewer number of crops and applied more water to cotton and cotton based cropping system as compared to others. During high rain fall year, as in the year 2005-06, as the expectation of an assured availability of more groundwater grew, groundwater was used more indiscriminately not only to more crops in the cropping systems but also to the different crops other than cotton followed in the watershed.

4.7 Depth to water table and cropping systems

The cropping systems practiced in the command of tube wells significantly differ in groundwater extraction. Fluctuation in groundwater level is affected by groundwater recharge and discharge activities. In other words, the agricultural activities in the catchment do have a bearing on the water level movements in the wells, given rainfall pattern and other climatic conditions. This line of argument presupposes a close relationship between the cropping system in the well command and the fluctuations in the depth to water table in that particular well. In a catchment establishing this relationship could go a long way in planning the agricultural activities, particularly in grey and dark zones to check the exploitation trend and avoiding the emergency situation, in other areas.

Depth to groundwater table and the cropping systems followed was, therefore, examined to test the significance of this relationship.

4.7.1 Hypothesis

The null hypothesis tested was that

i) The depth to water table did not change with the cropping system practiced.

ii) The cropping systems practiced in the tube well command were not affected by the depth to groundwater table

4.7.2 Data set and technique used

To test these hypotheses, data set on cropping system in a tube well command and the average depth to groundwater in the well was compiled and mapped individual tube well wise. About 35 to 40 wells in the watershed are under continuous observation to monitor the changes in the water level in the wells. These comprise of bore wells (open wells) and dug wells (tube wells). While most of the tube wells are being used for irrigation, open wells remain unused. Data on cropping systems practiced in the command of the wells was superimposed on the data pertaining to the water tables movement on corresponding wells. A sub-set of wells from amongst the total wells with both information available were identified and data on average depth to water table in the well and the cropping system practiced in its command during the corresponding year were compiled for the period under study. The data on average depth to groundwater table and the cropping systems practiced during the years 2003-04, 2004-05 and 2005-06 was compiled for 36, 30 and 16 wells, respectively. This variation in data points, as explained, was due to unavailability of matching information on both parameters for all the wells under observations in the watershed. Univariate Generalized Liner Model (GLM) analysis was used to test the hypothesis.

4.7.3 Results

During the year 2003-04, the water table depth varied from a minimum of 11 m in paddy mono crop system to a maximum depth of 38 m in cotton mono crop. The average depth to water table in cotton based cropping systems, however, worked out to be 29 m. During 2004-05, the variation in water table depth was in the range of 11 m in cotton_castor_paddy-fennel-wheat and 39 m in cotton_cumin. On the other hand, during high rainfall year, 2005-06, water table depth varied from 14 m in cotton_castor-fennel to 34 m in cotton_castor-fennel-wheat_cumin. The high rainfall during 2005-06 resulted in better groundwater recharge and hence, the depth to water table was comparatively less during this year as compared to the previous years. Cotton in kharif and fennel and wheat in rabi were the prominent crops accounting for change in water table depth.

4.7.3.1 Variation in depth to water table explained by cropping system

In the Univariate GLM analysis, the cropping system practiced was taken as independent factor explaining variation in annual average depth to water table in the tube wells.

The test of homogeneity of error variances confirmed (Table 4.12) that the error variances of groundwater were not homogeneous across the cropping systems. Since the GLM analysis does perform even for the data set not meeting homogeneity assumption for small sample size, the data set were analyzed with this procedure.

The F statistics of the Univariate GLM analysis confirmed the significance of the relationship (Table 4.13). The variation in cropping systems practiced in the tube well command during the year significantly explained the change in average depth to water table in the well in all the years, including the year of abnormally high rain fall. This rejected our first null hypothesis. It was, therefore, inferred that the annual average depth to groundwater table was significantly affected by the cropping systems in the tube well command. The model specification showed that 95, 88 and 97 percent variation in depth to water table were explained by the cropping system in the tube well command. For the pooled data regression analysis this value was 94 per cent.

4.7.3.2 Variation in cropping systems explained by depth to water table

Further, to examine whether the depth to water table had affected the cropping system followed by farmers in the respective tube well command, the cropping system was regressed over the annual average depth to water table for the individual years and the years taken together (pooled data).

The analysis again confirmed the significance of the relationship between the two variables. The cropping systems in the tube well command was significantly affected by the change in average depth to water table in the well (Table 4.14). This rejected the second null hypothesis and confirmed that the water table depth in the wells affected the crops and crop combination adopted by the farmers in the tube well command. The model specification suggested a fairly good proportion of change in cropping systems practiced explained by the depth to water table in tube well command (48 to 64 per cent in different year). For pooled data the value of adjusted R squared worked out to be 0.45 confirming the significant relation ship.

4.7.4 Discussion and policy implications

The analysis done in this section established that 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 practiced by the farmers in the tube well command. The latter relationship being stronger than the former. This analysis leads us to interpret that manipulation of cropping systems practiced in a catchment could, in some way, manipulate the falling groundwater table. This is more so in particular areas approaching the brown and black zone of water exploitation.

One of the policy implications of this could be regulating permit license for well construction particularly in groundwater exploitation zone with falling water table looking at the prevailing crops and cropping system. With a close monitoring and building a comprehensive data base on the cropping systems practiced and water table depth, the groundwater regulating authority of the state could be able to frame relevant guidelines to further stop the drilling of well given a particular cropping system being practiced in an area or suggest the change in the prevailing system(s) by suitable policy when permitting to exploit the groundwater.

Another implication of this could be manipulating the electricity tariff structure based on the prevailing crops and cropping systems in area with falling groundwater tables. Once a close relationship between crops and water table depth is established and crops accounting for change in water table depth such as cotton, fennel and wheat in the study area, are identified, the electricity tariff in groundwater use for irrigation could be structured in a fashion that excess exploitation of groundwater in those crops is discouraged. The present policy of charging the flat tariff with high subsidy based on capacity of motor used for extracting groundwater should be coupled and adjusted with the prevailing major cropping system in the brown and dark zones of heavily exploited areas such as Mehsana and Banaskantha districts in North Gujarat. This would also take care of the non-viability of groundwater use (IWMI-Tata Water Policy Programme, 2004) in such heavily subsidized electricity tariff scenario. Wherever crops accounting for variation in water table are predominant, a premium in the electricity be added in the existing tariff leaving the other minor crops to correct the situation of groundwater mining. This will have direct implication on the sustainability of this precious resource, which otherwise is over-exploited in the region because of the highly subsidized power supply (Shaheen and Shiyani, 2005).

4.8 SUMMARY AND DISCUSSION

The results obtained through the Univariate Generalized Linear Model (GLM) analysis are summarized as under,

i) The annual groundwater extraction and cropping systems practiced in the tube well command had 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 $m^3 acre^{-1}$ (Poor rainfall year, 2003-04) in cotton + maize inter crop to 13440 $m^3 acre^{-1}$ (High rainfall year, 2005-06) 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 about farmers' preference of crops was taking up more number of crops in the cotton based system with increased 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 tube well command. The latter relationship being stronger than the former.

Farmers have a tendency to change their crop pattern towards more number of crops if they get access to well irrigation in the watershed. While cotton and cotton based cropping systems dominated the irrigated area under well irrigation, with the availability of groundwater they increased area under other crops like fennel, cumin and wheat, which can not be grown without water. This confirms our first hypothesis about the farmers' tendency to shift to water intensive crops with the availability of groundwater. This finding is similar to the observations made elsewhere. Maharashtra's well owners' behaviour was also reported to be similar (Dhawan, 1986). He reported that farmers attempted to diversify their rainfed crop pattern by enlarging area under such crops that are normally not growable without the aid of irrigation. In contrast to Dhawan's finding in Maharashtra, where food crops gained prominence once access to well irrigation was established, cash crops like cotton and cotton based cropping systems were prominent groundwater irrigated crop system in the watershed studied.

The cropping systems served by individual wells are significantly related to the groundwater extracted from the wells as revealed by the analysis. While this confirmed the second hypothesis, it has several implications. The cropping systems with high groundwater extraction must be identified and manipulated in terms of expansion/ reduction of area depending on the groundwater extracted per unit area and the groundwater availability in areas identified as high groundwater exploitation zone (Centre for water policy, 2005). Cotton mono cropping and cotton based cropping system turned out to be the biggest competitor for extracted groundwater during normal rainfall year (2003-04). With higher rainfall, more crops entered in the cropping system extracting higher volume of groundwater. The tendency of farmers to increase the intensity of irrigation with higher availability of groundwater raises question mark on sustainability of the resource, particularly in state like Gujarat where 19 districts are reported to be under falling groundwater trend.

From a mean groundwater extraction of 700 – 780 m^3acre^{-1} during the normal rainfall year, the mean extraction increased five times to 3493 m^3acre^{-1} during the high rainfall year. This also confirms the third hypothesis about the groundwater extraction and the availability/ recharge of groundwater during the period of above normal rainfall.

4.9 CONCLUSION AND POLICY IMPLICATION

The analysis revealed that variation in groundwater extraction across the cropping systems irrigated by the tube wells is significant over the period. Not only the mean annual groundwater extraction and the cropping systems practiced in the watershed are significantly related but also, in general the mean groundwater extraction estimated from the model are significantly different among the cropping systems. Cotton and cotton based cropping systems are the major cropping systems followed in the watershed. The mean annual groundwater extraction level varied from 18.60 m^3acre^{-1} in cotton + maize inter crop to 13440 m^3acre^{-1} in Cotton-castor-fennel-cumin-summer pearl millet cropping systems. Among the cropping systems, while fennel and paddy mono cropping systems had significantly less groundwater extraction, the cotton based systems had significantly more than mean annual groundwater extraction in the watershed. The mean annual extraction showed an increasing trend over the period 2003-04 through 2005-06. However, in terms of proportion of variance in groundwater extraction in the watershed, cotton mono cropping system explained the maximum variance, followed by cotton-fennel, cotton-castor and cotton-castor- cumin.

The introduction of Bt cotton has not only reduced the risk of pest attack, thereby, improving the profitability of the cotton crop and cotton based cropping system but also made groundwater a heavily exploited resource in such areas, where accessibility to groundwater has increased. The semi-arid tropics of Gujarat, already with falling groundwater level, become more vulnerable with respect to groundwater exploitation and, therefore, raise questions on sustainability of the resource stock under the ground. The policy implication can be suggested in terms of premium on prices paid for groundwater extraction for crops and cropping systems with high groundwater extraction in such area to check the unlimited exploitation of groundwater stock so that increased recharge of the stock during years of good rainfall adds to this under ground stock rather than getting extracted as observed in the watershed.

4.10 LIMITATIONS OF THE WORK

The limitation of the present work is its geographical coverage for further generalization of the findings. Further, there is a trade off between resource use efficiency and profitability of the enterprise depending on groundwater exploitation, on the one hand and resource sustainability on the other. The present study takes caution in making the recommendation about premium on groundwater extraction price by the controlling authority on groundwater development. Such a study, if undertaken, to understand the trade off and its magnitude in varying geo-hydrological context can lead to situation specific policy implications for sustainable groundwater management.

4.11 FUTURE WORK

A future extension of the present study would be to examine the prevalent cropping systems in the existing resource endowment scenario in terms of the trade off between present profitability and sustainable stock in the future. This information would help formulate policy implications regarding banning the crop systems requiring heavy irrigation or replacing them with the crop systems with less water intensive use.

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Table 4.1: Major crops irrigated from groundwater in the watershed, 2003-04

Crop	Area (acre)	No. of irrigations provided	No. of farms	Total volume of groundwater extracted (m^3)
Cotton	202.2	206	35	211683.19
Paddy	11.8	35	6	2111.7
Castor	21.4	49	8	5321.48
Cotton+urad	0.7	4	1	14.48
Fennel	23.9	68	9	8278.88
Cotton+Maize	5.0	5	2	127.02
Drumstick	3.1	15	1	2431.00
Sunflower	27.5	37	5	5169.69
Cumin	4.3	5	1	111.14
Wheat	6.2	20	3	635.09
S. pearl millet	10.3	35	6	1833.84
S. sorghum	0.6	7	1	22.22
Lady's finger	0.6	5	1	15.87
Bitter gourd	0.6	8	1	15.87
Total	318.6	499		237771.57

Table 4.2: Major crops irrigated from groundwater in the watershed, 2004-05

Crop	Area (acre)	No. of irrigations	No. of farms	Total volume of groundwater extracted (m^3)
Cotton	389.1	422	56	388706.00
Paddy	19.5	36	6	1646.96
Castor	64.5	203	22	24358.30
Fennel	37.0	119	13	9548.66
Cumin	27.7	54	10	3515.64
Wheat	37.5	82	11	7053.37
Sargawa	5.00	160	1	1876.88
Sunflower	4.00	7	1	57.50
Isabgol	5.0	4	1	41.10
Summer Pearl millet	15.0	29	7	892.99
Total	631.9	1107		437067.23

Table 4.3: Major crops irrigated from groundwater in the watershed, 2005-06

Crop	Area (acre)	No. of irrigations	No. of farms	Total volume of groundwater extracted (m^3)
Cotton	239	511	52	236585.00
Paddy	5.5	7	2	3750.00
Castor	44.5	148	18	91440.00
Fennel	104	339	39	177440.00
Cumin	37.0	81	15	37750.00
Wheat	14.5	51	7	22550.00
Isabgol	1.0	5	1	2000.00
Summer Pearl millet	46.7	110	19	90585.50
Summer sorghum	8.5	23	4	20070.00
Groundnut	2.6		1	2436.00
Potato	2.6		1	6480.00
Total	505.9	1275		691086.00

Table 4.4. *Test of equality of error variances[$] in groundwater extraction*

F	df1	df2	Significance probability
Year 2003-04			
3.833	19	59	0.000
Year 2004-05			
2.989	23	55	0.000
Year 2005-06			
5.982	27	51	0.000
Year 2003-04 to 2005-06			
6.331	52	184	0.000

[$] Design – cropping system

Table 4.5. *Significance of Variation in annual groundwater extraction by the crops and cropping system, GLM Univariate test*

Dependent variable: Groundwater

Source	Sum of squares	df	Mean square	F	Significance probability
Year: 2003-04					
Model [a]	1739875239.29	20	86993761.96	9.281	0.00
Crops	1739875239.29	20	86993761.96	9.281	0.00
Error	553048437.27	59	9373702.33		
Total	2292923676.57	79			
[a] Adjusted R squared = 0.68					
Year: 2004-05					
Model [a]	102959919.94	24	4289996.66	110.15	0.00
Crops	102959919.94	24	4289996.66	110.15	0.00
Error	2142042.44	55	38946.23		
Total	105101962.37	79			
[a] Adjusted R squared = 0.97					
Year: 2005-06					
Model [a]	1589401261.0	28	56764330.7	39.67	0.00
Crops	1589401261.0	28	56764330.7	39.67	0.00
Error	72982319.0	51	1431025.8		
Total	1662383580.0	79			
[a] Adjusted R squared = 0.93					
Year: 2003-04 to 2005-06 (Pooled analysis)					
Model [a]	1669259825.69	53	31495468.40	31.90	0.00
Crops	1669259825.69	53	31495468.40	31.90	0.00
Error	181644291.81	184	987197.23		
Total	1850904117.51	237			
[a] Adjusted R squared = 0.87					

Table 4.6: *Contrast in mean groundwater extracted by crops and cropping system*

Source	Sum of squares	df	Mean square	F	Significance level
Year: 2003-04					
Contrast (Crops)	1024238163.2	19	53907271.7	5.75	0.00
Error	553048437.3	59	9373702.3		
Year: 2004-05					
Contrast (Crops)	53949020.9	23	2345609.6	60.2	0.00
Error	2142042.4	55	38946.2		
Year: 2005-06					
Contrast (Crops)	625469487.0	27	23165536.5	16.2	0.00
Error	72982319.3	51	1431025.8		
Year: 2003-04 to 2005-06 (Pooled analysis)					
Contrast (Crops)	1011100747.49	52	19444245.14	19.69	0.00
Error	181644291.81	184	987197.28		

Table 4.7: *Cropping systems and mean groundwater extraction (m^3/acre), 2003-04 to 2005-06 (Pooled data)*

S. No.	Cropping system	Mean annual extraction (m^3/acre)	Significance estimate
1	Cotton pure#	1353.7	0.000
2	Cotton, fennel#	2926.3	0.000
3	Cotton, castor#	1524.6	0.000
4	Summer pearl millet	176.2	0.595
5	Cotton, castor, fennel#	6083.7	0.000
6	Fennel alone#	910.3	0.016
7	Cotton, cumin#	1918.1	0.000
8	Cotton, fennel, cumin#	3319.2	0.000
9	Castor alone	417.2	0.402
10	Paddy alone#	189.7	0.703
11	Cotton, castor, fennel, cumin, wheat, summer pearl millet, isabgol#	6893.3	0.000
12	Cotton, summer pearl millet#	1765.3	0.002
13	Wheat, paddy	763.3	0.185
14	Cotton, castor, fennel, summer pearl millet#	9340.0	0.000
15	Cotton, fennel, summer pearl millet#	6081.0	0.000
16	Cotton, castor, summer pearl millet#	5890.0	0.000
17	Cotton, summer sorghum#	3996.0	0.000
18	Cotton, castor, wheat#	1922.1	0.007
19	Sunflower alone	223.4	0.751
20	Wheat alone	776.0	0.271
21	Cumin pure	115.65	0.869
22	Cotton + maize inter crop	18.6	0.979
23	Cotton, castor, fennel, cumin, summer pearl millet#	13440	0.000
24	Cotton, castor, fennel, cumin#	7860.0	0.000
25	Cotton, sunflower	1862.5	0.062
26	Cotton, castor, cumin#	2040.4	0.041
27	Castor, fennel, cumin, summer pearl millet#	6960.0	0.000
28	Cotton, fennel, cumin, wheat, summer pearl millet#	5840.0	0.000
29	Cotton, drumstick#	5290.5	0.000
30	Cotton, fennel, wheat#	5280.0	0.000
31	Cotton, paddy, summer pearl millet#	4880.0	0.000
32	Cotton, cumin, summer sorghum#	4440.0	0.000
33	Castor, fennel, summer pearl millet#	4128.0	0.000
34	Cotton, ground nut, potato#	4094.0	0.000
35	Sunflower, drum stick	1195.7	0.230
36	Cumin, summer sorghum#	3300.0	0.001
37	Fennel, summer pearl millet#	2640.0	0.009
38	Fennel, cumin#	2400.0	0.017
39	Cotton, wheat, paddy	1513.8	0.129
40	Sunflower, fennel	804.5	0.419

41	Cotton, castor, fennel, cumin, wheat, paddy#	2163.0	0.031
42	Cotton, castor, fennel, wheat, paddy#	2143.4	0.032
43	Castor, fennel, wheat, paddy	1229.6	0.217
44	Cotton, castor, cumin, wheat	1448.7	0.147
45	Cotton, sunflower, fennel	1243.1	0.212
46	Cotton, cumin, summer pearl millet	1237.0	0.215
47	Cotton, wheat, summer pearl millet	1053.3	0.290
48	Castor, fennel, wheat	842.0	0.398
49	Castor, wheat, paddy	829.5	0.405
50	Fennel, wheat, paddy, summer pearl millet	346.4	0.728
51	Castor, cotton + black gram inter crop	292.9	0.768
52	Summer pearl millet, vegetables	108.0	0.91
	Total	1666.5	

Significantly different from mean annual extraction in the watershed

Table 4.8: *Cropping systems significantly affecting groundwater extraction, 2003-04*

Dependent Variable: Groundwater extraction

Cropping system	**Mean annual extraction (m^3/acre)**	**Significance probability**	**Eta Squared$**
Cotton, castor*	2058.2	0.000	0.649
Cotton, fennel*	1885.3	0.000	0.700
Cotton, castor, fennel*	1731.0	0.000	0.396
Cotton, sunflower*	1862.5	0.000	0.431
Cotton, castor, cumin*	2040.4	0.000	0.476
Cotton alone*	1320.0	0.000	0.901
Sunflower, drumstick*	1195.7	0.000	0.238
Cotton, wheat, paddy*	1513.8	0.000	0.334
Sunflower, fennel*	8045.1	0.005	0.124
Castor, fennel, wheat, paddy*	1229.6	0.000	0.248
Fennel alone*	440.6	0.006	0.113
Sunflower alone	223.4	0.261	0.021
Castor alone	263.9	0.185	0.030
Paddy alone	189.7	0.178	0.031
Summer pearl millet alone	221.7	0.056	0.061
Castor, cotton + black gram	292.9	0.297	0.018
Wheat alone	112.1	0.689	0.003
Cotton + maize	18.6	0.925	0.000
Summer pearl millet, vegetables	108.0	0.699	0.003
Total	718.0		

significant at 5%

$ proportion of variance in the dependent variable that is explained by differences among groups.

Table 4.9: *Cropping systems significantly affecting groundwater extraction, 2004-05*

Dependent Variable: Groundwater extraction

Cropping systems	**Mean annual extraction (m^3/acre)**	**Significance probability**	**Eta $ squared**
Cotton, drum stick*	5290.53	.000	.929
Cotton, castor, fennel, cumin, wheat, paddy*	2163.02	.000	.686
Cotton, castor, fennel, wheat, paddy*	2143.44	.000	.682
Cotton, castor, wheat*	1922.12	.000	.775
Cotton, castor, fennel*	1586.05	.000	.540
Cotton, castor, cumin, wheat*	1448.76	.000	.495
Cotton, castor*	1436.62	.000	.897
Cotton, cumin*	1337.20	.000	.770
Cotton, fennel, cumin*	1272.07	.000	.602
Cotton, sun flower, fennel*	1243.16	.000	.419
Cotton, isabgol*	1237.01	.000	.417
Cotton, fennel*	1149.82	.000	.649
Cotton alone*	1072.39	.000	.855
Cotton, wheat, summer pearl millet*	1053.29	.000	.341
Cotton, summer pearl millet*	871.96	.000	.415
Castor, fennel, wheat*	842.05	.000	.249
Castor, wheat, paddy*	829.48	.000	.243
Castor alone*	570.45	.000	.233
Fennel, wheat, paddy, summer pearl millet	346.38	.085	.053
Fennel alone	266.47	.182	.032
Wheat, paddy	245.01	.085	.053
Cumin alone	115.65	.411	.012
Summer pearl millet alone	85.28	.457	.010
Total	787.64		

significant at 5%

$ proportion of variance in the dependent variable that is explained by differences among groups.

Table 4.10 *Cropping systems significantly affecting groundwater extraction, 2005-06*

Dependent Variable: Groundwater extraction

Cropping systems	**Mean annual extraction (m^3/acre)**	**Significance probability**	**Eta Squared** $
Cotton, castor, fennel, cumin, summer pearl millet*	13440.0	.000	.712
Cotton, castor,fennel,summer pearl millet*	9340.00	.000	.705
Cotton, castor, fennel, cumin*	7860.00	.000	.458
Cotton, castor,fennel*	7558.66	.000	.824
Castor, fennel, cumin, summer pearl millet*	6960.00	.000	.399
Cotton, castor, fennel, cumin, wheat, summer pearl millet, isabgol*	6893.33	.000	.661
Cotton, fennel, summer pearl millet*	6081.00	.000	.503
Cotton, castor, summer pearl millet*	5890.00	.000	.487
Cotton, fennel, cumin, wheat, summer pearl millet*	5840.00	.000	.318
Cotton, fennel, wheat*	5280.00	.000	.276
Cotton, paddy, summer pearl millet*	4880.00	.000	.246
Cotton, fennel, cumin*	4684.00	.000	.474
Cotton, cumin, summer sorghum*	4440.00	.001	.213
Castor, fennel, summer bajari*	4128.00	.001	.189
Cotton, ground nut potato,*	4094.00	.001	.187
Cotton, summer sorghum*	3996.00	.000	.304
Cotton, fennel*	3630.66	.000	.684
Cotton, summer pearl millet*	3552.00	.005	.147
Cumin, summer sorghum*	3300.00	.008	.130
Cotton, cumin*	3080.00	.001	.206
Fennel, summer pearl millet*	2640.00	.032	.087
Fennel, cumin*	2400.00	.050	.073
Wheat, paddy	1800.00	.139	.043
Cotton alone*	1744.00	.000	.294
Fennel alone	1594.66	.025	.095
Wheat alone	1440.00	.234	.028
Cotton, castor	1250.00	.301	.021
Total	3493.0		

* Significant at 5 %

$ proportion of variance in the dependent variable that is explained by differences among groups.

Table 4.11 *Comparison among mean groundwater extraction by cropping systems*

Cropping system		Significance probability of difference between mean extraction levels*
Year 2003-04		
Cotton mono cropping	Paddy mono cropping	0.000
	Castor mono cropping	0.000
	Cotton-castor	0.002
	Fennel mono cropping	0.000
	Cotton + maize inter cropping	0.000
	Sun flower mono cropping	0.000
	Summer pearl millet mono crop	0.000
Cotton-castor	Paddy mono cropping	0.005
Year 2004-05		
Cotton mono cropping	Cumin mono cropping	0.000
	Castor mono cropping	0.002
	Wheat-paddy	0.000
	Summer pearl millet mono crop	0.000
Cotton-castor	Cumin mono cropping	0.001
	Summer pearl millet mono crop	0.000
	Wheat-paddy	0.001
	Castor mono cropping	0.014
Year 2005-06		
Cotton mono cropping	Cotton-fennel	0.001
Cotton-fennel	Fennel mono cropping	0.010

* Significant at 5 %

Table 4.12: *Levene's test of homogeneity of error variances[a] in depth to water table*

'F' statistics	df1	df2	Significance prob.
Year 2003-04			
2.157	16	19	0.050
Year 2004-05			
1.586	17	12	0.211
Year 2005-06			
7.176	9	6	0.013

Table 4.13: *Cropping* system explaining variation in average depth to water table in the watershed

Dependent Variable: Av. depth to water table

Source	Sum of Squares	Df	Mean Square	F	Significance prob.
Year 2003-04					
Model[b]	29827.47	17	1754.55	47.69	0.00
CROP_SYS	29827.47	17	1754.55	47.69	0.00
Error	698.95	19	36.78		
Total	30526.43	36			
[b] Adjusted R Squared = 0.95					
Year 2004-05					
Model [b]	16401.36	18	911.18	13.70	0.00
CROP_SYS	16401.36	18	911.18	13.70	0.00
Error	798.13	12	66.51		
Total	17199.5	30			
[b] Adjusted R Squared = 0.88					
Year 2005-06					
Model [b]	8651.15	10	865.11	70.89	0.00
CROP_SYS	8651.15	10	865.11	70.89	0.00
Error	73.21	6	12.20		
Total	8724.36	16			
[b] Adjusted R Squared = 0.97					
Year 2003-04 to 2005-06					
Model [b]	55047.1	37	1487.5	35.2	0.00
CROP_SYS	55047.1	37	1487.5	35.2	0.00
Error	1939.9	46	42.17		
Total	56987.0	83			
[b] Adjusted R Squared = 0.94					

Table 4.14: *Annual average depth to water table explaining change in cropping systems practiced*

Dependent Variable: Cropping system code

Source	Sum of Squares	df	Mean Square	F	Significance prob.
Year 2003-04					
Model [b]	1070.81	1	1070.81	34.0	0.00
WELL_DEP	1070.81	1	1070.81	34.0	0.00
Error	1101.79	35	31.48		
Total	2178.00				
[b] Adjusted R Squared = 0.48					
Year 2004-05					
Model [b]	2139.12	1	2139.12	41.4	0.00
WELL_DEP	2139.12	1	2139.12	41.4	0.00
Error	1547.8	30	51.6		
Total	3687.00				
[b] Adjusted R Squared = 0.57					
Year 2005-06					
Model [b]	499.28	1	499.28	29.75	0.00
WELL_DEP	499.28	1	499.28	29.75	0.00
Error	251.71	15	1.78		
Total	751.00				
[b] Adjusted R Squared = 0.64					
Year 2003-04 to 2005-06					
Model	15504.589	1	15504.589	68.863	.000
WELL_DEP	15504.589	1	15504.589	68.863	.000
Error	18462.411	82	225.151		
Total	33967.000	83			
a Adjusted R Squared = 0 .45					