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3.1 RESEARCH DESIGN

3.1.1 Selection of the case study area

The present study aims to study groundwater extraction pattern in respect of prevailing crops and cropping system through rainfall and groundwater availability and model its optimization. Therefore, the study area was selected for special purpose. One purpose was to provide theoretical and quantitative support in terms of policy interventions to better manage the groundwater in a catchment. The other goal was to give suggestions to farmers about rational allocation of irrigation water and thus saving in the use of precious groundwater for its sustainable use. To achieve these goals, the case study selected, had to fulfill the following criteria. It should cover a relatively varying rainfall and groundwater availability scenarios and thus the real time data set required should be readily available. It should have well documented secondary data set, and to support that, the necessary primary data set could be readily collected through field surveys. For instance, information should be available regarding hydrological studies and the relevant hydrological parameters of water resource system required in the study of this kind. Fulfilling these criteria, the Antisar watershed in Kapadwanj Taluk of Kheda district was the natural choice for selection as the study area.

3.1.2 Sample and questionnaire design and interview conduct

Data was collected through primary and secondary sources. Farm-household surveys were regularly conducted. A list of farmers owning tube wells was prepared and their irrigation water use pattern was studied. There are 139 tube wells in the watershed but all are not functional. Some of the tube wells surveyed in one year were found non-functional in the next year. Some other tube wells, which were non- operational during past years, became operational in recent years as groundwater table rose due to recharge efforts. So, groundwater extraction data were collected from all the wells which were functional in different years over a period of time. Next the information on groundwater extracted and the crop details in the tube well command were collected and mapped for the respective wells. Farmers in the irrigation area were questioned according to the designed questionnaire. The questionnaire for farmers consisted of two parts. The first part was related to farm characteristics, the second part was related to water use information. In the first part, the demography of the household, family characteristics, labor force, farmland, outlay, on-farm and off-farm income, agricultural inputs, and credit were listed. In the second part, crop input-output details, irrigation details, expenditures for purchasing modern irrigation equipment, expenditure of digging a tube well, and distance of filed from the water source were listed. The data on water table depth were collected from secondary source. These tube wells were under observation and water level in the wells was being recorded at Central Soil & Water Conservation Research & Training Institute, Research centre, Vasad.

3.2 STUDY AREA

The study was conducted in Antisar watershed of Kapadwanj taluk in Kheda district of Gujarat. North Gujarat, in western region, particularly has been reported to be in the throes of a water crisis (Postel, 1999). The groundwater use has been perennially in excess of the recharge as a result, North Gujarat has, in recent times, emerged as the example of unsustainable groundwater exploitation. This was the major reason to confine the study in Gujarat. In Gujarat, one watershed, a complete geo-hydrological unit, was selected. An Integrated Wasteland Development Project (IWDP), funded by Department of Wasteland Development, Ministry of Rural Areas and Employment, Govt. of India, was executed in Kapadwanj taluk of Kheda district of Gujarat. The watershed falls in Agro-ecological sub region No 6, i.e. semi-arid central Gujarat and is part of west coast – Gujarat plain physiographic region, which drains to seasonal river Kharva, a tributary to river Mahor flowing about 15 km away from the watershed. Predominant semi-arid condition of the area imposes the constraints of water resources. The major interventions included land leveling, pond renovation, dam repair, check dam construction and well recharge activities. Twenty three recharge filters and 16 check dams were constructed through active participation of the beneficiaries. 142 ha of land were brought under land levelling activities. The Antisar watershed comprises of 7 villages/ hamlets namely, Aminpura, Antisar, Dazi-bariya-nu-muwada, Dudhelilat, Kapadivav, Khodiyar Nagar, Motipura. About 500 families dependent on agriculture and animal husbandry have participated in development activities of the watershed. The population of the watershed consists of 1413 adults and 691 children. They hail from Patel, Desai, Bariya, Backward class, Buxi panch and other communities. The average age of the family head (male) is worked out to be 44 years, majority (83%) of whom were educated up to 10th standard. The average family size is 4.2, which is dominated by males. The over-all education level in the area is fairly good. Average land holding in the watershed area is 3.5 ha. The land value in the area is Rs. 55000/- acre for irrigated land and Rs 38000/- per acre for un-irrigated land. Only 28% people availed crop (short term) loans, averaging Rs 36000/- with no amount outstanding. Long-term loan was availed by 17% people mainly for digging well and buying tractor. Of the average loan amount, 42 % was still outstanding at the time of benchmark survey. Agriculture is the main source of livelihood, hence major part of income comes from this source. However, medium and large farmers also earned a little income from service and business. The average annual rainfall of the Antisar watershed is 837 mm based on 20 years (1983-2004) data distributed over an average of 30 number of rainy days. Average runoff potential of the area is estimated to be 273 mm that corresponds to a modest 33 per cent of the annual rainfall. Since there is no source of irrigation, groundwater is used for irrigation of crops. In a situation of rainfall deficit, groundwater is used as a supplementary source of irrigation during kharif season and the primary irrigation source during rabi and summer season. Dug wells and bore wells are used to extract groundwater. There is a net work of wells around the water storage structures for providing irrigation to agricultural crops.

Total cropped area is 586.05 ha, accounting for 76.2 per cent area of the watershed (Kumar et al., 2004). Kharif crops are generally grown under rainfed conditions. The main *kharif* crops, viz; maize (*Zea mays L.*), cotton (*Gossypium hirsutum*), pearlmillet (*Pennisetum typhoides*), pigeonpea (*Cajanus cajan*), sorghum (*Sorghum vulgare*), and upland paddy (*Oryza sativa*) are mostly grown under rainfed conditions. The supplemental irrigations are given in crops like cotton and maize. The major rabi crops are castor (*Ricinus communis*), cumin (*Cuminum cyminum*), fennel (*Foeniculum vulgare*) and wheat (*Triticum vulgare)*. Groundwater withdrawal through tube wells and dug wells is the only source of irrigation. Some of the minor summer crops like pearlmillet and fodder are also irrigated.

3.3 METHODOLOGY: HYPOTHESIS, TECHNIQUE AND DATA COLLECTION

Farmers take different crops based on market price and personal choice. Still the individual choice of crops is also governed by groundwater availability. During the period of limited groundwater availability, the choice of crops to be sown is confined to a few crops such as maize, cotton and to some extent castor. With the availability of more groundwater the number of crops in their cropping system increases as observed in the watershed and the inclusion of new crops, in such a scenario is governed by prevailing prices. This means, within a broad framework of market prevailing in the area, the individual and group behaviour about selection and number of crops taken is governed by availability of groundwater in the aquifer. The groundwater availability in the aquifer is reflected in the groundwater depth. Farmers seem to be aware of the depth from which they withdraw water. Personal surveys and frequent talks with the farmers in the watershed confirmed the awareness of local farmers about water table depth and, in turn, as a proxy, groundwater availability. Accordingly, farmers select the crops and cropping system as well as volume of groundwater extraction. Similarly, while the choice of crops in a tube well command is affected by the groundwater depth, the groundwater depth itself is also affected by the aggregate number of crops and cropping system sown in the catchment command. Since, the volume of groundwater extracted affects the depth of groundwater in wells, the groundwater extraction is related to crops and cropping system through changes in groundwater depth. This implies that volume of groundwater extraction not only governs the crops and cropping system to be taken in a well command but is also governed by crops sown in the well command.

3.3.1 Framing hypothesis

These inter relationships between crops, groundwater depth and groundwater extraction are, therefore, proposed to be studied by examining the following hypothesis,

I) Selection of crops and cropping system is governed by the groundwater depth within a broad framework of market prevailing in the area.

II) Groundwater depth is affected by the crops and cropping systems grown in the tube well command.

III) Crops and cropping systems are strongly related to the volume of groundwater extraction.

IV) The volume of groundwater extracted by the selected crops and cropping systems in tube well command make distinct groups based on mean volume of groundwater extracted.

Establishment of these hypotheses makes it mandatory to identify the crops and crop combinations which withdraw the volume of groundwater different from the mean groundwater extraction in the watershed for policy implications. This leads to identification of the distinct crop groups based on the mean volume of groundwater extracted in tube well command.

Once these hypotheses are tested, the marginal productivity of water can be estimated for those crops identified in terms of higher groundwater extraction with further implications for water saving, inter-season and intra-season, from groundwater sustainability view point. The implications of groundwater extraction on stock of groundwater in the aquifer can, then, be examined in terms of groundwater depth to draw implications for groundwater availability in future. Different scenarios of groundwater extraction can be visualized for initial groundwater depths and volume of groundwater extraction to study the behaviour of groundwater stock over a period of time.

3.3.2 Techniques used

Hypothesis I envisages examining the relationship between crops and the groundwater depth with causal relationship. The groundwater depth governs crops sown in the well command in a stochastic resource availability scenario. While groundwater depth is a quantitative variable, crops and cropping system is categorical variable. Among the various techniques, Univariate Generalized Linear Model was used as it not only examines the relationship between the quantitative and categorical variables but also establishes the causal relationship between the two variables. For the purpose of analysis, data on groundwater depth of the tube wells and crops sown in their command were used for 2003-04, 2004-05 and 2005-06. The crops and cropping system was coded and used as dependent variable. This was regressed on the groundwater depth, the independent variable. Establishment of this relationship implies that groundwater depth can be a decision variable to suggest the crops and cropping systems that can be grown in the well command. This has direct implications for areas defined as grey and dark zones by the Central Groundwater Board.

Hypothesis II proposes to examine the association and causal relationship between groundwater depth and crops but in this case groundwater depth is proposed to be taken as dependent variable and is to be regressed over crops, the categorical variable. This is also proposed to be tested with the Univariate GLM technique. Examination of this hypothesis implies that those cropping systems significantly affecting the groundwater depth ought to be discouraged through product price and other policies such as putting premium on groundwater use in areas under such crops. This issue is proposed to be examined in detail in subsequent analysis where marginal values of water applied to the prominent crops have been examined.

Hypothesis III follows from hypothesis II. The crops and cropping systems affect the groundwater depth as envisaged by hypothesis II and the depth of groundwater in wells affects the groundwater extraction by farmer due to cost constraint. It is therefore hypothesized that crops and cropping system are not only related to groundwater extraction but also this relationship is causal. Hence, cropping systems were coded and considered as independent variable. Groundwater extraction, the quantitative variable was taken as dependent variable and regressed over crop codes. This was also achieved using Univariate GLM technique as this technique has strong features to analyze such type of data set, as discussed in the previous section.

The sequel to examining the causal relationship between the crops and groundwater extraction in tube well command is whether the crops and cropping systems make distinct groups based on mean groundwater extraction volume in the watershed. This was proposed to be examined through hypothesis IV. The hypothesis envisages studying the discrimination of different cropping systems in terms of the mean annual groundwater extraction in the command of the tube wells. Among the several techniques available to test this hypothesis Discriminant Analysis was used as this procedure is most effective when group membership (cropping system in this case) is truly categorical variable. Had group membership been based on the values of continuous variable, procedure like linear regression would have been considered to take advantage of the richer information offered by the continuous variable itself.

Next, identification of the distinct crops and cropping systems in terms of groundwater extraction envisages grouping the crops into respective groups. The criteria for grouping can be that groups are of similar kind in terms of a variable of interest, which is groundwater extracted in the present study. For this, cluster analysis was used. This is an exploratory data analysis tool which aims at sorting different crops and cropping system into groups in a way that the degree of association between two cropping systems is maximal if they belong to the same group and minimal otherwise, based on the mean annual groundwater extraction.

Further, to estimate marginal values of water in different crops at crop growth stages with implications for saving in water use, production function technique was used. This is widely used technique for examining the issue of marginal productivity of the resources used to produce an output. Further this is the most appropriate technique to compute the marginal values of a resource such as groundwater, which has no direct market. The values of such a resource can be estimated from the output, in production of which the resource is used and the output has a direct market. The output has a value in the market where it is traded. Therefore, based on the value of output and the marginal productivity of the resource in the production of that output, the marginal value of groundwater is estimated.

Finally, optimal control theory in deterministic framework has been used to examine the behaviour of groundwater stock, in terms of fluctuation in water table depth, as a result of groundwater extraction. Different levels of groundwater extraction were evaluated and its impact on rate of change in groundwater depth was examined with resource sustainability view point. Geo-morphologic studies of the aquifer has reported (Sharda, 2006) presence of different depths of water bearing strata. The implications of groundwater extraction from different depths are proposed to be studied using this framework.

3.3.3 Data collection

Both primary and secondary data have been used in the study. The primary data required for examination of the hypotheses have been collected from the field regularly over the period of three years, 2003-04 to 2005-06. The input output details of crops harvested in the tube well command along with groundwater extraction for individual irrigation event based on tube well discharge have been collected from the field. All the farms owning functional tube wells and irrigating crops with groundwater in the three years have formed the sample for data collection. The farms for which data on crop input and output were found inconsistent were dropped from the analysis. The total number of farms considered in the final analysis is 79, 92 and 86 for the years 2003-04, 2004-05 and 2005-06, respectively. The data on crop input output have been collected for the whole agricultural year. 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). The data have been collected on crop-wise input details such as seeds, fertilizers, chemicals, human, bullock and machine use. In addition, data on yield of crops, and groundwater pumping details, such as schedule of irrigations (numbers, date of water application, bore well running hours during different irrigations), tube well command area with cropping system details in each tube well command was collected. During *kharif* season, groundwater was applied only as supplemental irrigation and data collected include details of water applied at different crop growth stages both through rainfall as well as supplemental irrigations.

In addition, the water table depth in the wells under observation at Central Soil & Water Conservation Research & Training Institute, Research Centre, Vasad was collected from secondary source, that is records of the Research Institute.

Organization of manuscript

Chapter IV details the examination of hypotheses I, II and III relating crops and cropping system with groundwater depth and extraction. Hypothesis IV examining cropping system discrimination in terms of groundwater extraction is covered in chapter V. The marginal productivity analysis is described in detail in chapter VI and optimal control framework, in chapter VII.