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Farmers and Social Perspective on Optimal Crop Planning for Ground Water Sustainability: A Case of Punjab State in India

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SUMMARY

Punjab is one of the most fertile states in India with agriculture as its largest industry. The state is ideal for wheat, rice, sugarcane, fruits and vegetables. The share of agriculture in gross state domestic product (27 per cent) is higher than the national average of 18 per cent during 2014-15. In recent years a drop in productivity and profitability has been observed, mainly due to excessive use of natural resources. Most important problem in Punjab is the rapidly falling water table on which almost 72 per cent of the agriculture depends. The groundwater is falling by a meter or more per year. To ensure sustainable use of groundwater and to sustain productivity and profitability, this study presents optimum crop plan for Punjab state in India. Market price, economic price (net effect of subsidy) and natural resource valuation (NRV) have been used to maximize the net returns for Punjab farmers. The study has used plot-level cost of cultivation survey data for the triennium ending 2010-11. Linear Programming based model has been developed to examine various options of conserving water from farmers as well as social perspective. Ground water constraint has been varied by decreasing its availability in steps of 5 per cent starting from the existing ground water use of 31.6 Billion Cubic Meter to the replensihable limit of 20 Billion Cubic Meter. The results revealed that the area under paddy, a water intensive crop, has reduced from 7 to 59 per cent in different optimal crop plans. The study recommends that under the current level of technology and policy scenario, ground water savings can be increased up to 10 per cent of the existing use while maintaining net gains to society positive. To increase water savings beyond this level, technological improvements and policy interventions are required.

Keywords: Groundwater, Sustainability, Optimal crop plan, Punjab.

1. INTRODUCTION

Agriculture is the prime mover of economy of Punjab and contributed 27 per cent to the Gross state domestic product during 2014-15 which is higher than the national average of 18 per cent. Globally, Punjab produces nearly 1 per cent of rice, 2 per cent of wheat and 2 per cent of cotton, and leading all the states in per hectare yield of all these crops (State Pb 2013). As per NSSO, 2014, Punjab produces Rs. 10862 per household monthly income from cultivation (net receipt), which is three time more than the national average (Rs 3081 per household).

Agricultural growth in Punjab slowed down from 4.6 per cent in 1980s to 2.5 per cent in 1990s and to 2.3 per cent in 2000s. Similarly, growth of crop sector decreased from 4.3 per cent in 1980s to less than 1.1 per cent in 1990s, with a little improvement to 1.5 per cent in 2000s. The overall agricultural growth in the State during 11th Five Year Plan (2007-12) has been estimated at 1.6 percent against a national average of 3.4 percent (GoPb, 2013). The Punjab agricultural sector has lost its place among the fastest growing state agricultural economies in the country; having been bypassed by a number of other states, including Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, and West Bengal (IFPRI 2007). The slow down is a matter of concern for Punjab's economy that's highly dependent upon agriculture to an extent of 65 per cent. Thus, sustainability in agricultural production and the

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natural resource base are under threat, as there is over-exploitation of land, water resources, and degradation of the environment and ecology (Singh 2004, 2012, Sidhu *et al.* 2010).

Over the past several decades, there has been a gradual shift in the cropping pattern of the state from the former mix of traditional crops such as wheat, maize, pulses and vegetables to the monoculture of rice-wheat crop rotation (Shergill 2007; Singh 2011, Singh J. 2013). Presently, paddy-wheat rotation jointly occupies 80 per cent of the gross cropped area of Punjab. Dominance of paddy-wheat cropping pattern is accompanied by shifting irrigation sources from surface to ground water irrigation as tube wells are considered more reliable and flexible (Sarkar 2014). Notwithstanding, the share of groundwater irrigation in net irrigated area has increased from 55 per cent to 72.58 per cent during the period of 1970-71 to 2012-13. The extensive use of groundwater as a source of irrigation for producing water-intensive crops particularly paddy has resulted into severe depletion of ground water table in most parts of the state (Kaur *et al.* 2015). Several empirical studies have revealed a swift depleting groundwater-table in most parts of the state due to 72 per cent higher ground water draft over the sustainable limit of 20 Billion Cubic Meter (BCM) (GoI 2011; Srivastava *et.al.* 2015). Such a situation threatens the sustainability of water resources and hence, the agricultural productivity in Punjab, calling for an efficient and sustainable management of water resources (GoPb 2004).

To ensure sustainable use of groundwater in Punjab agriculture, it is necessary to revisit existing cropping pattern and develop optimum crop plan for the state which maximizes net returns not only to the farmer but also to the society as a whole. Many studies in the past attempted development of optimal cropping pattern for maximizing net returns from farmers' perspective (Kaur *et al.* 2010, 2015; Husain *et al*. 2007; Pradhan 2012). However, the studies ignored the social perspective and hence did not assess any benefits or losses to the society.

The present study attempts to fill this void and develop optimum crop plan for Punjab by maximizing net returns based on three alternative approaches i.e. market prices; economic prices (net out effect of subsidy) and natural resource valuation (NRV) considering environmental benefits like biological nitrogen fixation and greenhouse gas costs. The three price scenarios are based on the argument that the crop profitability should be linked with social cost, i.e. input subsidies and effect on environment and natural resource (Raju *et al*. 2015). Computing returns at market prices of inputs represents income to the producer, but not to the society as it is a direct cost to the society. Thus, while computing the returns to the society, subsidy has been suitably accounted for. Further, positive and negative environmental externalities need to be accounted, that has a direct bearing to the society. Linear programming model was formulated to propose optimal cropping pattern for maximizing net returns based on three different price scenariosfor given water supply situation. The study also attempts to safeguard savings of groundwater to ensure sustainable groundwater use in the Punjab agriculture by using sensitivity analysis.

2. DATA AND METHODOLOGY

The study is primarily based on data taken from the "Comprehensive Scheme for Studying the Cost of Cultivation (CoC) of Principal Crops'', Directorate of Economics and Statistics, Ministry of Agriculture, Government of India. Under this scheme, data were collected from a sample of 300 farm households in 30 tehsils spread across three agro-climatic zones of Punjab for the block year ending 2010-11. The other secondary data sources were used viz., Central Ground Water Board (CGWB), Ministry of Water Resources; Statistical abstracts of Punjab, various issues. Input and output coefficients and various return coefficients have been derived from the plot level data. Crop calendar year i.e. the production period of crops has been taken from Agricultural statistics at a glance, 2015.

2.1 Model Formulation

Linear programming (LP) is a powerful tool for farm management and planning and offers different ways to use limited resources under different set of objectives and constraints. Multi-crop model for two seasons- *rabi* and *khraif* has been formulated in LP for maximizing the net returns, minimizing the cost and minimizing the water usage by keeping all other available resources (such as cultivable land, seeds, fertilizers, human power, pesticides, capital etc.) as constraints.

Mathematically, model specifications for Punjab are presented by Equations 1-7:

$$Max\ Z = \sum_{c=1}^{n} (Y_c P_c - C_c)\, A_c \quad (1)$$

$$\sum_t \sum_c a_{tc}\, A_c \leq NS_t - OA_t \quad (2)$$

$$A_c \geq A\min_c \quad (3)$$

$$A_c \leq A\max_c \quad (4)$$

$$\sum_c w_c A_c \leq RWAA \quad (5)$$

$$\sum_c A_c \leq CI^*NS \quad (6)$$

$$A_c \geq 0 \quad (7)$$

In the above equations, *Z* denotes the total returns; Y_c denotes yield of a crop *c* in one hectare of land, *Pc* the price received for the crop *c*, *Cc* refers to the cost incurred to cultivate crop cin one hectare of land and A_c is the area under cultivation of crop *c*; a_{tc} is 0 or 1 depending on the absence or presence of the crop *c* in the month *t*; NS_t is net sown area during month *t*; OA_t refers to area under perennial crops; $Amin_c$ and $Amax_c$ refer to minimum and maximum area limits for a crop *c* respectively; w_c refers to actual water drafted per ha for a crop *c*; RWAA refers to ground water available limit; CI refers to cropping intensity; NS is the net sown area. The objective is to maximize the net returns based on the optimum crop plan. The RHS of the Equation 1 represents sum of net revenue obtained from the crops considered for the optimum model development.

In the present study net returns or performance of different crops has been assessed by comparing net returns under alternative scenarios. These are: (i) Market prices; (ii) Economic prices net of subsidies; and (iii) Income based on natural resource valuation technique (Raju *et al.* 2015). The above linear programming model has been executed under General Algebraic Modeling System (GAMS).

The *net return at market prices* was computed as the gross return (value of main product and by product) less variable costs (Cost A_1+ imputed value of family labour) actually paid and received by the farmer or imputed in some cases (DES; Rajni *et al.* 2015).

The *net return at economic prices* was calculated as the net return or income at market prices lesssubsidies on fertilizers and irrigation used in crop production. Fertilizer subsidy consists of subsidy on nitrogen (*N*) and combination of phosphorous (*P*) and potassium (*K*). The total irrigation subsidy includes canal, electricity and diesel subsidies and has been distributed over the selected crops based on crop area under irrigation.

The *net return based on natural resource valuation* (NR_{NRV}) technique accounts for nitrogen fixation by legume crops and GHG emission from crop production. As such NR_{NRV} was computed by adding value of nitrogen fixation by a crop at economic price of nitrogen (Value of *N*) and deducting the imputed value of increase in greenhouse gas (GHG) emission to the atmosphere.

(i) Land Constraint

Optimum use of land for each month is required. This can be achieved by having separate constraint equation (Equation 2 is a compact form of 12 equations one for each month). This helps to have separate sown area for each month and ensures that total cultivated area under selected crops in each month should be less than net sown area minus area under orchard crops. Further crop calendar matrix was maintained to represent the months covered by each crop from its sowing to harvesting. The present study modelled the 92 per cent of the existing GCA i.e. 7298 thousand hectares due to limitations in data availability.

(ii) Minimum and Maximum Crop Area Constraints

Crop planning model using LP primarily captures the supply side behavior specifically area response based on net returns and resource constraints ignoring the demand aspect. Such models tend to overestimate or underestimate the area allocations for some crops. As a consequence, a single crop may cover infeasible larger area (overestimation) or null or negligible area (underestimation).

In some modelling solutions, some major crops may drastically lose their relevance and the corresponding area allocations may become negligible. Then, even though estimates are robust and mathematically proven, such allocations may not be desirable and practically possible from the view point of food security of the country and livelihood security of the farmer because appropriate changes are required in policy framework of the country to adopt the optimum sustainable model. Similarly, area allocations for some minor crops may be overestimated ignoring the demand. Such an area allocation is again undesirable as it may lead to glut in the market. To avoid such undesirable overestimation or underestimation, assigning values to minimum and maximum area of the selected crops become essential in the model. To eliminate such practically undesirable solutions, concept of min, max constraints is used in the model as specified by the equations 3-4. Area constraints under the various crops has been determined based on (i) expert elicitation method, (ii) the existing land area allocations under different crops and (iii) recommendations in the crop diversification plan of Punjab government in 2013 (GoI 2013)

The crops which are cultivated by more than five plots were considered important for crop planning assuming that they may have potential for substitution for existing crops which may not be efficient in terms of natural resource utilization and optimum profitability. In the model, the selected crops are paddy, basmati, maize,green gram (moong), black gram (urad), redgram, groundnut, sesame, cotton, *Kharif* vegetables, *Kharif* fodder, wheat, barley, potato, pea, gram, sunflower, rapeseed, *Rabi* vegetables, *Rabi* fodder, sugarcane, lentil, kenaf and oelery.

(iii) Ground Water Constraints

Water is a scarce natural resource. The ground water usage should be less than or equal to replenishable ground water available for agriculture (RWAA) to ensure its sustainability. Data of RWAA is taken from Central Ground Water Board. Ground water constraint used in linear programming (LP) model for Punjab agriculture is presented in equation 5.

(iv) Coefficients of the Model

Various cost and return coefficients for each crop as used in equation 1 have been taken from the study Raju *et al.* (2015). The per hectare water usage (cum/ha) for individual crops has been taken from the study Srivastava *et al*. (2015).

Further to analyse the social cost and benefit, subsidy on diesel and electricity have been accounted for estimation of groundwater extraction cost (Srivastava *et al.* 2016). Average subsidized and unsubsidized cost of extracting one cubic meter (cum) groundwater for irrigation in Punjab was estimated as Rs 0.46 and Rs. 0.91 per cum respectively for the period triennium ending (TE) 2010-11. Thus the estimated subsidy comes out to be Rs 0.45 per cum in Punjab.

2.2 Sensitivity Analysis

Sensitivity analysis has been carried out to model the optimal cropping patterns for three different price scenarios (viz., market price, economic price and NRV)and altering the availability of existing groundwater for irrigation. Different GW scenarios are: (1) no groundwater constraint i.e. business as usual; (2) restricting groundwater to the existing use; (3) step wise reducing the existing GW by 5 per cent till replinishable limit of 20 BCM. As our model is applicable to 92 per cent of the existing GCA, the adjusted replinshable limit is 18.51 BCM. The comparison of estimates with existing cropping pattern provides the insights regarding the required changes in crop mix to ensure sustainability of groundwater.

3. RESULTS AND DISCUSSIONS

3.1 Status of Cropping Pattern and Groundwater Resources in Punjab

There has been a significant shift in the cropping pattern of the state during the past decades. The crop pattern was directed by the state policy during green revolution in Punjab. The share of paddy in gross cropped area (GCA) has increased from 6.87 per cent during 1970-71 to 26.74 per cent in 1990-91, that further rose to 35.88 per cent in 2010-11. Wheat occupied about 40.49 per cent of GCA in 1970-71 that further increased to 43.52 per cent in 1990-91 and since then it hovered around 44.58 per cent. The increase in rice cultivation has been at the cost of maize, groundnut, millets and cotton, while area under wheat has been expanded by shifting it from gram, rapeseed and mustard, barley etc. The proportionate area under cotton in 1970-71 was 7 per cent of GCA and increased to 9.34 per cent in 1990-91. The area under cotton has been adversely affected during mid 1990's due to adverse weather and pest attack. The share of cotton in GCA went down to 5.97 per cent in 2000-01. However with the introduction of Btvarieties its share in GCA got expanded to 6.25 per cent in 2010-11. The area under pulses and oilseeds has recorded a sharp decline. Pulses share in GCA has dropped from 7.29 per cent in 1970-71 to 1.53 per cent in 1990s and to 0.18 per cent in 2010-11. Similarly, oilseeds share in GCA has declined from 5.41 per cent in 1970-71 to 0.50 per cent in 2010-11. Areas under commercial crops like sugarcane and potato have not remained stable. Thus the cropping pattern of the state has been dominated by rice and wheat cultivation mainly because of relative profitability with minimum production and marketing risk as compared to other crops. However, this mono-culture has created a number of serious problems in the state especially depletion of water table.

Groundwater resources in the state have taken a sharp dip during the past 20 years. The total annual ground water resources in the state are assessed to be about 20.35 Billion Cubic Meter (BCM). The present ground water development (ratio of gross ground water draft for all uses to net ground water availability) in the state is 172% with an annual deficit of 14.56 BCM as per latest data of Central Ground Water Board (GoI 2014).

The provision of free electricity for agriculture is a major reason for over-pumping. During 1980's, average groundwater level was at 8 meter below ground level (m bgl), that declined to about 15 m bgl during 2013 (Fig. 1). It is observed that since the introduction of free electricity policy for agriculture in 1997, groundwater level has been diminishing drastically at an alarming rate of 42 cm per annum due to irrational groundwater extraction. Thus the deterioration in groundwater resources is the outcome of technology and policy led shift in cropping pattern i.e. towards paddy, irrigation source towards groundwater and energy source towards electricity in Punjab. Paddy emerged as the most water-guzzling crop consuming 45 to 88 per cent higher groundwater than other crops (Srivastava *et al*. 2015).

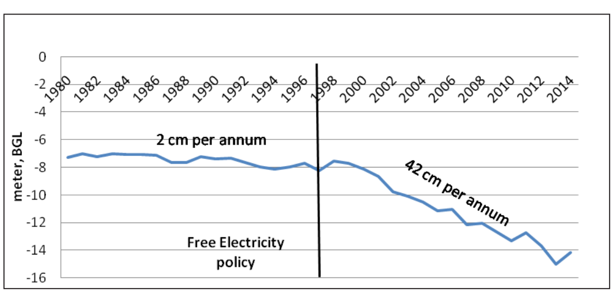

Fig. 1: Average Groundwater level in Punjab during 1980-2014
Source: CGWB, GOI

3.2 Optimum Crop Plan under Alternative Prices and Ground Water Scenarios

Taking into account both economic and social perspective of declining ground water table, the present study attempts to develop optimum crop plan not only for maximizing net returns but also for efficient and sustainable management of water resources. As mentioned net returns has been maximised using three alternative approaches i.e. Net returns at market prices (NR_{MP}); Net returns at economic prices (NR_{EP}) (net out effect of subsidy) and Net returns based on natural resource valuation (NR_{NRV}) considering environmental benefits like biological nitrogen fixation and greenhouse gas costs (Raju *et al*. 2015). The estimates of various models as mentioned in methodology section are presented in the rest of this section.

Table 1 presents the scenario of unrestricted ground water use for irrigation. It is evident from the table that if business as usual scenario continues further, the acreage under paddy crop has tendency to increase from 2760 thousand hectares (existing area) to 3584 thousand hectares (optimal plan) in the *kharif* season at the expense of other crops (shown by positive direction of change). In the *rabi* season, area under vegetables shows a positive change to the tune of 39,000 hectares with decline in area under all other *rabi* crops. The optimal cropping pattern remains unchanged in all the three price scenarios (Table 1). Thus, the area allocation is more skewed towards water intensive crops. This suggests that if ground water policy regarding irrigation is not checked, it will lead to doubling of ground water extraction (37 BCM) with reference to the replenishable level of 20 BCM as recommended by CGWB. It will further increase water extraction cost due to further declining of water table.

Table 2 presents the scenario of restricting groundwater use to existing level of 31.62 BCM which is 92 per cent of actual total ground water draft of 34.17 BCM. It is observed that optimal area under paddy and cotton tends to increase because of relatively higher returns in comparison to other *kharif* crops. In this scenario, both basmati (800 thousand hectares) and cotton (715, thousand hectares) crops has attained the maximum potential area as both the crops offer relatively higher returns. This area increase is consistent with the diversification plan of Punjab government in 2013 which recommended area

Table 1. Optimum crop model for unrestricted GW use: Business as usual scenario

Crops	Existing area (000 ha)	Optimum area (000 ha)			Direction of Change
		Market Price	Economic Price	Natural Resource Valuation	
Kharif Season					
Paddy		2784	2784	2784	
Basmati		800	800	800	
Paddy (including Basmati)	2760	3584	3584	3584	+ + +
Maize	136	102	102	102	_ _ _
Cotton	483	386	386	386	_ _ _
Vegetables	57	29	29	29	_ _ _
Others*	28	17	17	17	_ _ _
Rabi Season					
Wheat	3520	2954	2952	2952	_ _ _
Vegetables	65	104	104	104	+ + +
Potato	69	35	35	35	_ _ _
Oilseeds (Rapeseed+Sunflower)	51	26	26	26	_ _ _
Others**	39	28	30	30	_ _ _
Sugarcane	70	35	35	35	_ _ _
Gross Cropped Area	7298	7298	7298	7298	

Source: Author's estimates based on CoC data TE 2010-11

Note: * Includes moong, urad, redgram, groundnut, sesame and fodder

**Includes barley, pea, gram, lentil, kenaf, oelery and fodder

Table 2. Optimum crop model for GW use restricted to existing: Ground water existing scenario

Crops	Existing area (000 ha)	Optimum area (000 ha)			Direction of Change
		Market Price	Economic Price	Natural Resource Valuation	
Kharif Season					
Paddy		1984	1984	1984	
Basmati		800	800	800	
Paddy (including Basmati)	2760	2784	2784	2784	+ + +
Maize	136	102	102	102	_ _ _
Cotton	483	715	715	715	+ + +
Vegetables	57	29	29	29	_ _ _
Others	28	17	17	17	_ _ _
Rabi Season					
Wheat	3519.7	3425	3425	3424	_ _ _
Vegetables	65	104	104	104	+ + +
Potato	69.4	35	35	35	_ _ _
Oilseeds (Rapeseed+Sunflower)	51	26	26	26	_ _ _
Others	39.1	28	28	30	_ _ _
Sugarcane	70	35	35	35	_ _ _
Gross Cropped Area	7298	7298	7298	7298	

Source: Author's estimates based on CoC data TE 2010-11

expansion of about 2 lakh hectares under cotton and basmati each. In the *rabi* season, area under vegetables has increased from the existing 65 thousand hectares to 104thousand hectares. The area under wheat in the optimal plan has declined by 3 per cent while the area share in other crops viz., potato, oilseeds and sugarcane has declined almost by 50 per cent. Overall, the optimal plan has allocated about 48 per cent more area to cotton, 1 per cent increment to paddy crop, 60 per cent in *rabi* vegetables and minor decline in wheat acreage. This scenario is important because it suggests there is scope for improving the farm returns by increasing the efficiency under the prevailing resource use.

CGWB has earmarked replenishable water limit of about 20 BCM for irrigation in the state. However reducing water use by 41 per cent of the existing use is not attainable because of drastic changes in cropping pattern resulting into sharp decline in farm returns. Therefore, water use has to be reduced gradually to prepare the farmer to develop their own coping strategy. Thus various optimal production plans has been developed by reducing water usage stepwise so as to evaluate the repercussions on cropping pattern from farmers and social perspectives.

3.3 Sensitivity Analysis: Sustainability of GW Irrigation Use and Optimal Crop Mix

Sensitivity analysis helps to determine how sensitive the optimal solution is to changes in data values. In the study, sensitivity analysis has been done to address the issue of sustainability of GW use by developing new crop plans, which may ensure sustainable water-use without much adversely affecting the net returns from farming. The different crop plans were formulated and evaluated by gradual reduction in the GW use by 5-25 per cent of existing limit in steps of 5 per cent and sustainability scenario of 20 BCM (Fig. 2). However, in the study the results of few models have been elaborated due to the space constraint.

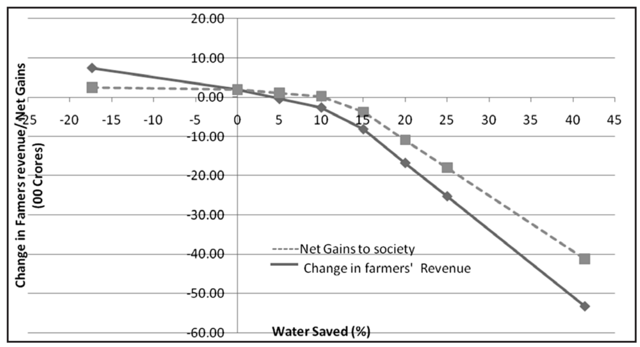

Fig. 2: Sensitivity Analysis at market prices: Farmers and Social Perspective

Table 3. Optimum crop model by reducing 10% of existing GW use limit: Ground water Sustainable scenario

Crops	Existing area (000 ha)	Optimum area (000 ha)			Direction of Change
		Market Price	Economic Price	Natural Resource Valuation	
Kharif Season					
Paddy		1531	1531	1530	
Basmati		800	800	800	
Paddy (including Basmati)	2760	2331	2331	2330	_ _ _
Maize	136	102	102	102	_ _ _
Cotton	483	715	715	715	+ + +
Vegetables	57	29	29	29	_ _ _
Others (including fodder)	28	17	17	17	_ _ _
Rabi Season					
Wheat	3519.7	3878	3878	3877	+ + +
Vegetables	65	104	104	104	+ + +
Potato	69.4	35	35	35	_ _ _
Oilseeds (Rapeseed+Sunflower)	51	26	26	26	_ _ _
Others (including fodder)	39.1	28	28	30	_ _ _
Sugarcane	70	35	35	35	_ _ _
Gross Cropped Area	7298	7298	7298	7298	

Source: Author's estimates based on CoC data TE 2010-11

The Table 3 presents the case of reducing GW use by 10 per cent i.e. 28.46 BCM. The optimal crop mix estimated under this model reduces the paddy acreage by 16 per cent i.e. from 2.76 million hectares to 2.331 million hectares at market prices. There were marginal differences in area allocation of paddy under three cases of market, economic and NRV prices. The area allocated to cotton has increased to the maximum area limit of 715 thousand hectares. In the *rabi* season, wheat and vegetables being the more profitable crops gained area by 10 and 60 per cent respectively. However the gross cropped area remained unaltered. Marginal differences were observed under different crops in alternative three price scenarios.

The case of reducing GW use by 20 per cent i.e. 25.29 BCM GW water available for irrigation is presented in Table 4. Under this scenario, as expected area under basmati has been fully utilized (800 thousand hectares) but area under non-basmati declined. As a result, total paddy area has declined by 30 per cent of the current area (from 2760 to 1934 thousand hectares). Positive change in the acreage of maize and cotton was observed due to favorable trade-off between water and net returns in these two crops. Like the case of previous model for *rabi* season, area under wheat and vegetables has further increased. The acreage of all others crops has declined in this model. Thus, gross cropped area has reduced from 7298 to 7124, 7110, and 7112 thousand hectares at market, economic and NRV prices respectively to achieve the savings of 6.33 BCM of water.

Table 5 presents the ideal ground water sustainability scenario where the optimum crop model for GW use has been restricted to replenishable limit of 18.51 BCM. This scenario is ideal case because the water draft is equal to water recharge. In this model, due to severe water constraint and paddy being the most water guzzling crop, area declined from the existing 2760 to 1143,000 hectares at market prices (59 per cent of existing area). This observation is inconformity with the diversification plan for Punjab to shift 1.2 million of paddy area to other crops like maize, cotton, sugarcane, pulses, and vegetables in *kharif* season (GoI 2013; GoPb 2013). However it is observed that due to higher net returns basmati area remains same as in earlier models. The area under maize and cotton has increased substantially by 60 and 48 per cent respectively.

In *rabi* season, the area under wheat (12%) and vegetables (60%) has increased significantly due to higher net returns. Since sugarcane is also water intensive crop, the optimal crop mix reduces its area to minimal allowable limit of 35,000 hectares. Besides, marginal differences in optimum allocated areas at three prices were observed. Thus for achieving the ideal replenishable limit of groundwater, there will be an overall reduction in GCA by 13 per cent.

3.4 Evaluation of Optimal Crop Plans: Farmers and Social Perspective

Ideal optimal crop plan may be identified as the one which does not disturb the natural resources beyond sustainable limit. Thus for sustainability perspective GW use should be less than or equal to replenishable limit of GW. Therefore, optimum crop plan given in Table 5 can be considered as ideal optimal crop plan. It is observed that in the ideal optimal crop plan, water is saved to the sustainable limit thus it is most desirable from the societal perspective. On the other hand,in business as usual scenario where water is unconstrained, the optimal model shows maximum returns to the farmers (Table 1). This is most preferred crop plan from the farmers' perspective. To strike a balance between the two perspectives, there is a need to evaluate and compare the farmers and social gains and identify the workable crop plan which can be accepted by both farmers and society. For this purpose, the gain matrix was estimated for various levels of GW use at three different prices market price, economic price and NRV with reference to the existing scenario (Table 6). Computational details of estimating gains can be referred in methodology manual (Rajni *et al.* 2015).

In the unrestricted GW use scenario, there has been increase in farmers revenue by 750 crores (2.66%) at market prices since the cropping pattern was skewed towards more water consuming and remunerative crops. The resultant over use of water is estimated to be 5.49 BCM which leads todepletion of water table (societal loss) and more water extraction cost of 253 crores. Besides, social gains are negative due to increased irrigation subsidy to the tune of 247 crores. The change in optimal farmer revenue at the economic prices and NRV were estimated by taking the base value of existing revenue at market prices. The returns at economic prices and NRV reflected the net effect of input subsidy costs and environmental

Table 4. Optimum crop model by reducing 20% of existing GW use limit: Ground water Sustainable scenario

Crops	Existing area (000 ha)	Optimum area (000 ha)			Direction of Change
		Market Price	Economic Price	Natural Resource Valuation	
Kharif Season					
Paddy		1134	1135	1135	
Basmati		800	800	800	
Paddy (including Basmati)	2760	1934	1935	1935	_ _ _
Maize	136	218	218	218	+ + +
Cotton	483	715	715	715	+ + +
Vegetables	57	29	29	29	_ _ _
Others (including fodder)	28	36	20	22	_ _ _
Rabi Season					
Wheat	3519.7	3945	3945	3945	+ + +
Vegetables	65	104	104	104	+ + +
Potato	69.4	34.7	35	34.7	_ _ _
Oilseeds (Rapeseed+Sunflower)	51	47.5	48	47.5	_ _ _
Others (including fodder)	39.1	28.05	28	28.05	_ _ _
Sugarcane	70	35	35	35	_ _ _
Gross Cropped Area	7298	7124	7110	7112	_ _ _

Source: Author's estimates based on CoC data TE 2010-11

Table 5. Optimum crop model for GW use restricted to replenishable limit: Ground water sustainability scenario

Crops	Existing area (000 ha)	Optimum area (000 ha)			Direction of Change
		Market Price	Economic Price	Natural Resource Valuation	
Kharif Season					
Paddy		343	345	344	
Basmati		800	800	800	
Paddy (including Basmati)	2760	1143	1145	1144	_ _ _
Maize	136	218	218	218	+ + +
Cotton	483	715	715	715	+ + +
Vegetables	57	29	29	29	_ _ _
Others (including fodder)	28	36	20	22	_ _ _
Rabi Season					
Wheat	3520	3945	3945	3945	+ + +
Vegetables	65	104	104	104	+ + +
Potato	69	35	35	35	_ _ _
Oilseeds (Rapeseed+Sunflower)	51	48	48	48	_ _ _
Others (including fodder)	39.1	28	28	28	_ _ _
Sugarcane	70	35	35	35	_ _ _
Gross Cropped Area	7298	6334	6319	6321	_ _ _

Source: Author's estimates based on CoC data TE 2010-11

Table 6. Gains due to optimum crop model over existing scenario for Sustainable water use in Punjab

(00'Crores)

Optimum Scenario	Change in GCA %	Existing Revenue	Optimal Net Returns	Farmer's Perspective			Social perspective				Net Gains
				Change in Farmers' Revenue	Farmer gain in terms of saving in GW extraction cost*	Total Farmer gains	Water Saved (bcm)	Social gains	Water Subsidy Saving**	Total Social Gains	
Unrestricted water use(Business as usual)											
Market Price	0	297	304	7.5	-2.53	4.94	-5.49	0	-2.47	-2.47	2.47
Economic Price	0	212	220	-76.9	-5	-81.88		85	0	84.63	2.75
Natural Resource Valuation	0	206	212	-84	-5	-89.03		90	0	90.45	1.41
Existing Scenario											
Market Price	0	297	298	1.9	0	1.89	0	0	0	0	1.89
Economic Price	0	212	215	-81.3	0	-81.26		85	0	84.63	3.37
Natural Resource Valuation	0	206	209	-87.1	0	-87.09		90	0	90.45	3.36
Sustainable water use(reduction of 10 % of existing GW use limit)											
Market Price	0	297	294	-2.6	1.45	-1.17	3.16	0	1.42	1.42	0.25
Economic Price	0	212	212	-84.6	2.87	-81.76		85	0	84.63	2.86
Natural Resource Valuation	0	206	207	-89.7	2.87	-86.85		90	0	90.45	3.6
Sustainable water use (reduction of 15 % of existing GW use limit)											
Market Price	0	297	288	-8.1	2.18	-5.93	4.74	0	2.13	2.13	-3.8
Economic Price	-0.04	212	207	-89.1	4.31	-84.79		85	0	84.63	-0.16
Natural Resource Valuation	-0.01	206	203	-93.8	4.31	-89.5		90	0	90.45	0.94
Sustainable water use(reduction of 20 % of existing GW use limit)											
Market Price	-2.4	297	280	-16.7	2.91		6.33	0	2.85	2.85	-10.9
Economic Price	-2.6	212	201	-95.3	5.7			85	0	84.63	-4.92
Natural Resource Valuation	-2.6	206	197	-99.6	5.7			90	0	90.45	-3.48
Sustainable water use(20 BCM)											
Market Price	-13	297	243	-53.2	6.03		13.11	0	5.9	5.9	-41.25
Economic Price	-13	212	175	-121.5	11.9			85	0	84.63	-24.96
Natural Resource Valuation	-13	206	172	-124.4	11.9			90	0	90.45	-22.06

*The average cost of extracting one cubic meter GW for irrigation is estimated as Rs 0.46 for TE 2010-11 at MP (Srivastava *et. al.*, 2016).

** The average subsidy of extracting one cubic meter GW for irrigation is estimated as Rs 0.45 for TE 2010-11 (Srivastava *et. al.,* 2016)

costs-benefits respectively. Net gains (summation of farmers and societal gains) under market, economic and NRV prices were estimated as 247, 275 and 141 crores respectively.

The model of GW use limited to the existing level (31.62 BCM), revealed that the optimal returns from farmers' perspective had changed by 189 hundred crores (0.64%) at market prices. Thus, there is a potential to increase the returns by reorienting the existing cropping pattern at prevailing level of water use with optimal plan recommended by this model. However there is no societal gains in terms of water or subsidy saving. At economic and NRV price, total farmers gains have decreased due to net effect of subsidy and loss of natural resources respectively,but the society benefits by 8463 and 9045 crores respectively. Net gains under market, economic and NRV prices were estimated as189, 337 and 336 crores respectively.

Appendix A. Coefficients used in development of optimal crop plan for Punjab

Crop	Existing area ('000 ha)	Minimum Area ('000 ha)	Maximum Area ('000 ha)	Net returns at market price ('00 crores)	Net returns at Economic Price ('00 crores)	Net returns at NRV ('00 crores)	Ground water draft (cum/ha)
Paddy	2229	0	2786.25	46198	33191	31353	8576.842
Basmati	560	0	800	53377	41789	39951	8674.086
Maize	136	102	217.6	12330	4949	4790	579.3112
Moong	8.7	4.35	13.92	7140	-41	2194	941.2076
Urad	2.9	1.45	4.64	-5016	-5757	-3522	744.8432
Redgram	3	1.5	4.5	19128	14722	18605	1986.874
Groundnut	2.2	1.1	3.52	3622	3129	7689	1706.611
Sesame	6.2	3.1	9.92	4690	2506	2391	839.1298
Cotton	483	386.4	715	42187	30530	30359	1863.515
Kharifveg	57	28.5	91.2	14543	-3744	-3979	2824.272
Khariffodder	5	5	7.5	3991	-4508	-418	2380.613
Wheat	3519.7	1759.85	4100	36244	25747	25564	1610.809
Barley	13	6.5	20.8	26431	18832	18832	2402.038
Potato	69.4	34.7	111.04	27138	8209	7974	1627.473
Pea	5	2.5	8	44549	33354	34646	1156.978
Gram	3	6.5	20.8	2633	-2366	774	1187.637
Sunflower	20	10	32	14127	7866	7751	1843.388
Rapeseed	31	15.5	49.6	14450	7556	7441	1204.734
Rabi Veg	65	32.5	104	48950	40357	40122	3236.839
Rabi fodder	5	5	10	7434	-4123	-33	3102.01
Sugarcane	70	35	112	26785	13521	13403	4810.352
Lentil	1.1	0.55	1.76	11134	11134	13369	152.3592
Kenaf	1	0	1.5	33560	27512	27512	3744.054
Oelery	1	0	1.5	54645	50750	50750	2063.342

If the water availability is decreased by 10 per centwith reference to its existing use, following positive changes are predicted viz., (i) restoring the water table to the level of saving of 3.16 BCM (ii) cost of water extraction for irrigation get reduced by 145 crores and 287 crores at market and economic price respectively . The average cost of extracting one cubic meter GW for irrigation is estimated as Rs 0.46 for TE 2010-11 (Srivastava *et al*. 2016). (iii) Society gains by savings in subsidy to the tune of 142 crores (Table 6). The anticipated negative changes are (i) at market price, reduction in farmers gain by 260 crores (0.89 %), however, this loss partially get compensated by saving in water extraction cost as discussed above and resulting in net loss of 117 crores. (ii) at economic and NRV price, society gains by 8500 and 9000 crores at the cost of farmers gains (negative) respectively.

Subsequently, net gains to the society are estimated by summing up total farmer gains and total societal gains. In Punjab, estimated net gains to the economy amounted to Rs 0.25 hundred crores at market prices, which went up to Rs 3.60 hundred crores at NRV prices (Table 6). Besides, saving of 3.16 BCM water leads towards sustainability of ground water.

Further, it is observed from the table that at 15 per cent, 20 per cent and 41 per cent (replenishable limit) reduction in GW use from the existing levels, the net returns from the farmers perspective decreased by 2.74 per cent, 5.62 per cent and 17.94 per cent respectively at market prices. Whereas, from the social perspective there were savings of water to the amount of 4.74, 6.33 and 13.1 BCM of water at respective scenarios of GW irrigation decrease by 15 per cent, 20 per cent and 41 per cent. However, it is observed that the net gains to economy become negative after 10 per cent reduction in GW from the existing use.

To compare and identify the suitable scenario, the results of the above sensitivity analysis are summarized in Fig. 2. Horizontal axis represents the water savings in per cent with reference to the existing GW use. Negative values on this axis represent over-exploitation of water i.e. business as usual scenario (no GW restriction) while the value zero refers to the case of existing GW use. Vertical axis represents change in farmers' revenue and net gain. Following observations are made:

(i) It is observed that with unlimited GW availability (17 per cent over exploitation of existing GW) there were more gains to the farmers than the society as at this point the curve for change in farmers revenue is above the net gains to the society.

(ii) As water savings are increased towards replenishable limit, changes in farmer's revenue declines. However rate of decline is lesser upto 10 per cent level of savings as compared to beyond this limit.

(iii) Net gains are positive up to 10 per cent of savings of water while it is negative beyond this level. However these net gains exclude the value of the water saved and its benefits to the society.

(iv) The gap between farmer's gains and the net gains widens with increasing level of water savings. However, beyond 10 per cent level, the rate of loss of farmers' revenue is faster than the society.

Thus it can be inferred that if the ground water extraction continues to be unregulated; it may bring more revenues to the farmers but lead to alarming situation in the years to come which may be much costlier. At the same time, we should not immediately switch to the scenario of replenishable GW use as it reduces the farmers gains drastically. However to move the first step towards achieving the sustainability of ground water resources, ground water savings can be increased upto 10% of the existing use at current level of technology and policy scenario. As observed in Table 6, at the scenario of 10% level, the optimal net returns to the farmers are 294 hundred crores in comparison to the existing 297 hundred crores. This reduction of 2.6 per cent in farmers' revenue needs to be compensated by appropriate policy changes and suitable support mechanism.

4. CONCLUSIONS

The current scenario in Punjab is a glaring example of groundwater over-exploitation. The water table is dropping at an alarming rate of 42 cm per annum which needs to be addressed by developing optimal crop plans at the earliest. To identify an optimal cropping pattern while considering the perspective of the society as well as farmers, net returns are estimated based on three different prices namely market, economic and NRV prices under different cases of water availability using sensitivity analysis. It has been observed that among the three price scenarios, existing market price scenario with unlimited GW is preferable from farmer's perspective but threatening from societal perspective.

It has been found that if the policies regarding GW extraction and electricity pricing continue then the exploitation of water tends to further increase by 5.49 BCM resulting in increase of net returns to farmers but aggravating the problem of GW sustainability and other natural resources.

Sensitivity analysis in this paper (reducing GW usage step wise by 5 per cent each from the existing use of GW) quantifies the social and private (farmers) benefits. Additional monitory value of water saved at each stage has not been added while estimating the social benefits. As expected, as water is constrained more and more, farmer's revenue followed declining trend while water savings showed upward trend. The area under water intensive crops like paddy tends to decrease giving way for lesser water consuming crops like cotton and maize in *kharif* season and wheat and vegetables in *rabi* season. The results revealed that the area under paddy has reduced by 16 to 59 percent as the model moved from the 10 per cent reduction of GW use from the existing to the replenishable limit of GW use in Punjab. It concludes that though sustainable and preferable from the society point, it is impractical to immediately enforce the farmers towards the use of GW upto replenishable limit because of estimated reduction in farmers revenue of about 4700 crores. But a small step, which can suitably balance the interest of both farmers and society, towards water saving is crucial for GW sustainability. In this regard, the study recommends 10 per cent reduction in GW use from the existing level. At this level, the optimal returns of the farmers are estimated to be less than the existing revenue by 260 crores. Partial losses are compensated by cost savings which would have incurred on extracting 3.16 BCM of water (10%). The remaining losses may be compensated by distributing the saved subsidies of about 142 crores to the farmers. Thus, as per farmer's perspective the losses can be fully compensated along with additional benefit of 25 crores to the society.

In the long run, to move towards sustainability scenario, set of policies need to be implemented to encourage the farmers to shift the cropping pattern towards high water productive crops, adopting efficient irrigation system like irrigation scheduling, tension-meter, drip irrigation, laser leveling etc. Adoption of suitable improved cultivation techniques like System of Rice Intensification, direct seeding of paddy, timely transplantation will further increase water productivity. Electricity can be suitably priced to promote judicious use of GW. Further, to promote suitable crop mix in Punjab, markets, infrastructure and credit availability need to be strengthened along with price assurance.

Disclaimer: The material, views and results presented in the paper are those of the authors and do not necessarily reflect in any way the views of the organizations to which the authors are affiliated.

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