Conjunctive Use of Surface and Ground Waters Using Non-linear Optimization in the Tumaria Extension Canal Command of Udham Singh Nagar District of Uttarakhand

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Abstract: **This study presents the development and application of two Non-linear Programming (NLP) models / plans for the seasonal optimal allocation of resources to maximize the annual return of the Tumaria canal command of Udham Singh Nagar district of Uttarakhand. This area comes under Tumaria Extension Main canal which originates from Tumaria dam. There are two distributaries and fourteen minors in the Tumaria extension canal network. The length of the main canal, distributaries and minors, and total length of canals of the study area are 10713, 25214 and 35927 meters respectively. The CCA of canal command is 14070 ha. Total 11 crops were included in the optimization plan. Plan1; the crop-wise proposed area of all crops in the command was less than or equal to existing area of a crop except fodder crops which was equal to existing crop area under fodder crops in command. Plan 2; the crop-wise proposed area of major crops in the command was greater than or equal to area required for the production of food for minimum consumption of population in the command while the crop-wise proposed area of fodder and vegetable crops were equal to existing area of a crop in the command; the crop-wise proposed area of minor crops in this Plan 2 was less than or equal to the area required for the production of food for minimum consumption of population in the command. Existing available groundwater was considered as the average of five years groundwater draft through minor irrigation structures (2010-2014). Twenty five percent, fifty percent, seventy five percent and hundred percent of the five years average of groundwater available for irrigation corresponding to semi-critical groundwater utilization development stage (90% of net groundwater recharge) as calculated in Table 1, was added to the existing available groundwater and the programme for Plan 1 and Plan 2 was run for these four additional levels of groundwater availability. The net annual return for existing cropping pattern, Plan 1 and Plan 2 with 100 percent of additional available groundwater; were obtained as Rs. 912.57 Million, Rs. 635.98 Million and Rs.708.36 Million, respectively. The proposed crop plan includes wheat, *masur*, pea, mustard, sugarcane and potato in *Rabi;* paddy, maize, *urad*, sugarcane and soybean in *Kharif,* and summer rice and sugarcane in *Zaid* season. The production function for different crops were taken from the existing literature.**

Keywords: Conjunctive use planning; nonlinear programming; production functions; canal command area.

I. INTRODUCTION

At present, the competition to have sufficient water in different sectors form a finite amount of available water is rapidly increasing and agriculture is found to be the biggest user of fresh water. The success and failure of crops is closely associated with the prevailing weather conditions. The uncertainty of rainfall and availability of water for irrigation play an important role in agriculture production. When availability of irrigation water is insufficient, appropriate irrigation scheduling may help in increasing the crop yields. A deficit in the availability of moisture to the crop at a certain stage of crop growth stage of crop growth may cause a greater reduction in the yield as compared to the deficit of same extent at other growth stages. Several factors are to be considered in irrigation planning, particularly when several crops are grown in the same command area in more than one season in a year. Two distinct decisions to be made are (i) how much water and land should be allocated to each crop at a seasonal level and at an inter seasonal level, (ii) how the strategy of allocation of water at each level would help to maximize net income from the command area.

Optimization models have been used extensively in water resources systems analysis and planning in canal command area (Loucks et al. 1981). The conjunctive use of groundwater and surface-water resources is necessary because the availability of one source of water over time and space may not be sufficient to fulfill all irrigation requirements (Harmancioglu et al. 2013). Generally the conjunctive use of water resources improves application water use efficiency and the regional environment of irrigated areas (Cosgrove and Johnson 2005; Liu et al. 2013). An-Vo *et. al.* 1 (2015) proposed an innovative nonlinear programming model for the optimization of profitability and productivity in an irrigation command area, with conjunctive water use options. Srivastava

and Singh (2015) formulated multi objectives optimization problem and solved using fuzzy programming approach (FPA) with linear, exponential and hyperbolic membership functions. Autovino *et. al.* (2016) proposed a methodology aimed to determine the optimal seasonal irrigation depth based on the crop production function, the field distribution uniformity, and economic considerations.

The study area is the Tumaria extension canal command. It covers Jaspur block of Udham Singh Nagar district of Uttarakhand and Thakurdwara block of Moradabad district of Uttar Pradesh. Most of the farmers in canal command area are following rice-wheat cropping system. Because of low cost of water they are still using the surface irrigation method and do not care to adopt the proper method of surface irrigation, drip irrigation or sprinkler irrigation. Poor design and management are generally responsible for inefficient irrigation, leading to wastage of water, water logging, salinization and pollution of surface and ground water resources. Non-uniform application of water results in water stressed conditions for crops in some parts of the field, while over-irrigation leads to wastage of water through runoff from at tail end and deep percolation at the head end of the field. Hence, this sector offers a major avenue for water saving.

This study was taken up to know the present status of land and water resources in the Tumaria extension command and to develop optimal crop plans with conjunctive use of canal and ground waters using non-linear optimization technique.

II. METHOD AND MATERIALS

Study Area and Data collection

The study area comes under Tumaria Extension Main canal which originates from Tumaria dam. It is located between latitude 28° 20' N and 29° 23' N and extends between longitudes 78° 24' E and 80° 08' E (Fig.1). The sources of Irrigation water in this area is a strong network of canal and ground water. There are two distributaries and fourteen minors. The length of the main canal, distributaries and minors, and total length of canals in the study area are 10713, 25214 and 35927 meters respectively. The CCA of canal command is 14070 ha.

The study area is characterized by two distinct seasons *Kharif* and *Rabi*. The *Kharif* season is from July to October and the *Rabi* season from November to February .The major crops grown are paddy, sugarcane, maize, and soybean in the *Kharif* season and wheat, potato, pea, and mustard in the *Rabi* season.

Weather data of 20 years, from 1995 to 2014 were collected from the meteorological observatory, G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. The discharge at the head of main canal, distributaries and minors; CCA of main canal, distributaries and minors; and cropping pattern were obtained from Irrigation Department, Kashipur, whereas data on number of minor irrigation structures were collected from statistical diary of Uttarakhand and Uttar Pradesh. Topographical maps of the study area were obtained from the survey of India, Dehradun.

Evapotranspiration

Evapotranspiration (ET) was estimated by adopting a two-step procedure. In the first step, daily reference Evapotranspiration (ET_O) was estimated by the Penman-Monteith method based on long-term meteorological data and in the second step, weekly crop coefficients (Kc) for each crop were used as per FAO guidelines (Allen *et al.* 1998) to calculated weekly crop Evapotranspiration (ET_{crop}) as

$$ET_{crop}=ET_0 \times K_c$$

Effective rainfall

Effective rainfall was calculated using USDA Soil Conservation Service method (Dastane, 1974) as

$$P_e = P_t\left(\frac{125 \quad .2\times P_t}{125}\right) \qquad \text{for } P_t < 250 \text{ mm, and} \qquad (2)$$

$$P_e = 125 + 0.1\times P_t \qquad \text{for } P_t > 250 \text{ mm} \qquad (3)$$

where P_e = effective rainfall in mm; and P_t = total rainfall in mm.

Net irrigation requirement

The net irrigation requirement (NIR) of the crop was estimated by field water balance.

$$NIR = ET_{crop} - (P_{eff}+G_e+W_b) \qquad (4)$$

where ET_{crop} = crop evapotranspiration; P_{eff} = effective rainfall; G_e = groundwater contribution; and W_b = stored soil water.

There was no change in storage of soil water before and after the crop duration and no contribution of groundwater and water table above the root zone.

$$NIR = ET_{crop} - P_{eff} \qquad (5)$$

Gross irrigation requirement (GIR)

The GIR was calculated by using following relationship:

$$GIR = \frac{NIR}{\eta} \times 100 \qquad (6)$$

where η = field application efficiency of the system (70%)

Optimization Model Formulation

Optimization of Modal using Nonlinear Programming Technique

The optimization modal was developed using nonlinear programming technique. The decision or basic variables, objective function and constraints of the model are described as below;

Objective function

The objective function of the area allocation model was to maximize the net return from the command area, as follows;

$$\text{Maximize} \qquad Z = \sum_{i=1}^{N} P_i(W_i, X_i) \tag{7}$$

$$\text{Where } P(W, X) = p \times Y(W) \times X - C \times X \tag{8}$$

p is the output price (Rs per Quintal) of the crop, X is the area (ha), C is the growing costs (Rs per ha), Y is yield (Quintal per ha), and W is the Net irrigation requirement (cm).

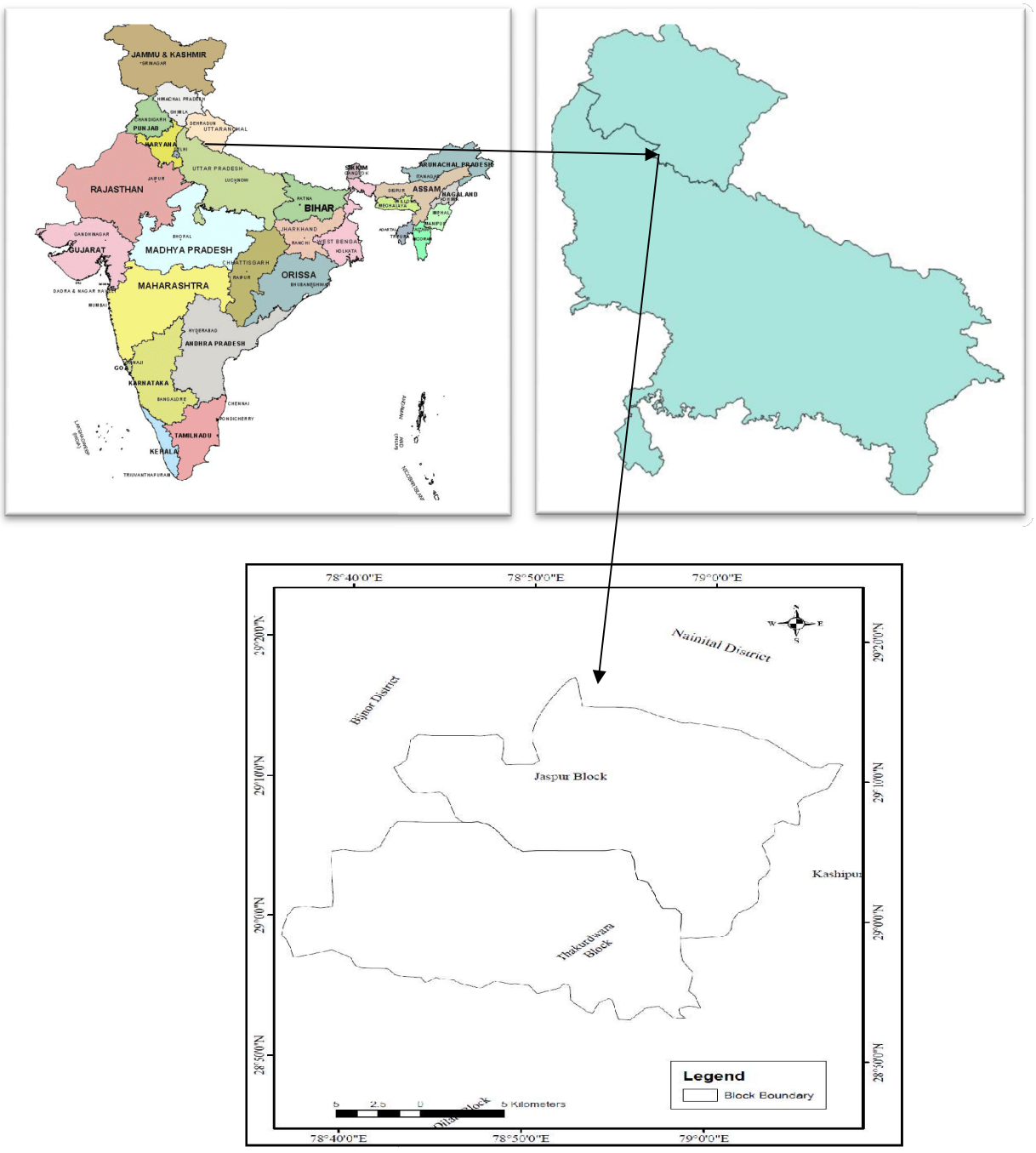

Figure 1: Index map of the study area.

The objective function was subjected to fallowing constraints.

Constraints

A) Cultivable land area constraint: Land allocated to various crops must not exceed the total cultivable area during the *rabi, kharif* and *zaid* seasons,

$$\sum_{i=1}^{N} X_i^j \leq \text{TA} \quad (9)$$

where X_i^j is area of crop i during season j and TA is the total cultivable area.

B) Water requirement constraints: The irrigation water requirement of all the crops in any season should not be greater than the total water available.

$$\sum_{i=1}^{n} W_i^J \; X_i^j \leq \text{CW}^k + GW^k \quad \text{i =1…n, j =1, 2, 3 k =1….12} \quad (10)$$

where W_i^j is the gross irrigation requirement for the production of crop i during season j, CW^k and GW^k are the canal water availability at field head and groundwater availability during month k = 1 for January to 12 for December.

C) Annual groundwater draft constraint: The total groundwater use in season j should not exceed the allowable groundwater extraction in the season j.

$$\sum_{j=1}^{3} GW^j \leq AGW \quad (11)$$

where AGW is the allowable seasonal groundwater extraction (ha-m) in the command.

D) Management considerations: Market conditions, machinery capacity of the farm, and climatic conditions restrict the minimum or maximum land acreages for certain crops such as rice to meet the regulations on local land use in the area.

(a) Lower bound

$$X_i \geq \mu_i^{min}\text{TA} \quad (12)$$

(b) Upper bound

$$X_i \leq \mu_i^{max} TA \quad (13)$$

where μ_i^{min} and μ_i^{max} are the minimum and the maximum fractions, respectively, of the cultivated area under crop i.

E) Non negative constraint

The non-negativity constraints which ensure the solution remain feasible,

$$X_i \geq 0 \quad (14)$$

Methodology

To obtain optimal cropping pattern, the eleven selected crops i.e. paddy, wheat, sugarcane, mustard, potato, pea, maize, *urad, masur*, soybean and summer rice were considered for command area. Evapotranspiration of crops of the study area was determined using Penman-Monteith method. Net irrigation requirement of crop was obtained by subtracting the effective rainfall from crop evapotranspiration. The weekly canal supply of water at the head, obtained from Irrigation Department, Kashipur was converted to seasonal water supply at canal head. The seasonal water supply thus obtained at canal head was converted to field head by taking 60 % conveyance efficiency. Plan1; the crop-wise proposed area of all crops in the command was less than or equal to existing area of a crop except fodder crops which was equal to existing crop area under fodder crops in command. Plan 2; the crop-wise proposed area of major crops in the command was greater than or equal to area required for the production of food for minimum consumption of population in the command while the crop-wise proposed area of fodder and vegetable crops were equal to existing area of a crop in the command; the crop-wise proposed area of minor crops in this Plan 2 was less than or equal to the area required for the production of food for minimum consumption of population in the command. Existing available groundwater was considered as the average of five years groundwater draft through minor irrigation structures (2010-2014) as calculated in Table 1. Twenty five percent, fifty percent, seventy five percent and hundred percent of the five years average of groundwater available for irrigation corresponding to semi-critical groundwater utilization development stage (90% of net groundwater recharge) as calculated in Table 2, was added to the existing available groundwater and the programme for Plan 1 and Plan 2 was run for these four additional levels of groundwater availability. The formulation of objective function was done using production function of crops through equation 7 and corresponding constrains, equations 9-14.

III. RESULTS

The developed nonlinear models were optimized using LINDO 16.0 optimization package to arrive at optimal allocation plan of cropping area, surface water and groundwater.

Cropping pattern

The crops grown and their existing sown area in the Tumaria extension canal command were obtained from the Statistical Diary of Moradabad and U. S. Nagar districts (2013-14). It indicated that maximum area was occupied by the paddy crop (10222.17 ha) followed by wheat (9926.85 ha), sugarcane (3064.10ha), summer paddy (315.05 ha), pea (309.16 ha), mustard (212.19 ha), *urad* (110.37 ha), potato (77.69 ha), *masur* (64.68 ha), soybean (41.92 ha), maize (1.65 ha), etc. The existing cropping area of paddy, wheat and

sugarcane were 72.65 %, 70.55 % and 21.78 % of the command area, respectively.

Water Resources

The available water resources in the study area were: surface water which was obtained from Tumaria Reservoir through Tumaria extension canal system and groundwater from minor irrigation system. The design discharge of Tumaria extension canal was 196 cusecs. It may be observed from Table 3 that the maximum and the minimum average monthly water availability at field head were 228 ha-m and 70 ha-m, in month of May and June, respectively.

Crop irrigation water requirement

The weekly irrigation water requirements for eleven crops being cultivable in the command were determined. The monthly net irrigation requirements were then estimated by adding the weekly irrigation requirement as per the standard meteorological weeks. The gross irrigation requirement was estimated by considering field application efficiency as 70 percent. The maximum and the minimum average seasonal gross irrigation requirements were obtained as 1287.26 mm and 68.03 mm for sugarcane and *urad,* respectively.

Groundwater Requirement

The difference between crop water demand and net canal water supply at field head was considered as net groundwater requirement. The maximum ground water requirement of 1674 ha-m was found in the month of October and the minimum was observed as 324 ha-m in the month of July. The annual groundwater requirement was 9522 ha-m. It can be observed from Table 1 that average net draft through minor irrigation structures was 3594.24 ha-m and maximum available groundwater for irrigation at semi-critical development stage for the command was 536.96 ha-m.

The cost of cultivation and prices of different crops

The cost of cultivation of various crops was taken from the Directorate of Economics & Statistics (2013-14). The price of crops viz for paddy, wheat, maize, mustard, soybean, sugarcane, potato, pea, *masur,* and *urad* has been considered as minimum support price, MSP.

Optimization of Plan using Nonlinear Programming Technique

The programme in LINDO 16.0 optimal resource utilization plan using production function for the maximization of net return from the crop activities, land and water resources for the canal command system, was run with existing cropping pattern of the command, Plan 1 and Plan 2. The net return was obtained as Rs. 912.57 Million with the existing cropping pattern in the command. The production functions of different crops of U. S. Nagar (Chandra, 2001) are given in Table 4. This table show that production function for wheat, paddy, *masur*, potato, pea, *urad*, summer rice and soybean are polynomials equation while for sugarcane, mustard and maize these functions are exponential in nature.

Optimal crop Plan 1 with non-linear programming technique (without summer rice) under available canal water and groundwater corresponding to existing groundwater development stage and different levels of additional available groundwater.

It may be seen from Table 5 that area allocated for wheat, pea, mustard, sugarcane, potato, kharif rice, maize, and *urad,* were 9545.60, 255.80, 114.92, 1180.54, 72.59, 0.00, 1.35, and 125.22 hectares, respectively, under available groundwater (corresponding to existing development stage). The area of sugarcane was found increased as 1436.34 ha with 100 % additional available groundwater utilization. This increased area of sugarcane resulted in decrease in area under other crops/ fallow land. Moreover, it may also be observed from Table 5 that there was a increasing trend in the area of sugarcane with the increase in utilization of additional available groundwater. However, the area of other crops did not change with the change in the utilization of additional available groundwater. This optimization model was also run with the area restriction of summer rice but this model did not allocate any area for summer rice.

Optimal crop Plan 2 with non-linear programming technique (without summer rice) under available canal water and groundwater corresponding to existing groundwater development stage and different levels of additional available groundwater.

The crop area allocated for different crops by the optimization model as per the minimum and the maximum area restrictions imposed for different crops may be observed from Table 6. *Masur*, pea, mustard, potato, maize, *urad* and soybean occupied 86.95 ha, 550.80 ha, 226.63 ha, 72.59 ha, 1.35 ha, 269.63 ha and 635.50 ha of area, respectively. The limit imposed for these crops was the food consumption requirement of the people in the command. These areas may be increase or decrease depending on per hectare yield of crop and additional water levels available for irrigation. Wheat occupied 12950.62 ha area during *Rabi* season under groundwater availability corresponding to existing development stage which has further decreased to 12949.90 ha with 100% increase in additional available groundwater for irrigation. The occupied area by *kharif* rice was 4062.02 ha with existing groundwater utilization development stage which has decreased to 3611.80 ha with 25% increase in additional available groundwater for irrigation and then these area under *kharif* rice was on increasing trend with the increase in 50% additional available groundwater for irrigation but remained same for 75% and 100% increase in additional available groundwater for irrigation. Further sugarcane area was found to be constant as 182.41 ha with different levels of increase in additional available

groundwater for irrigation. The net return for existing cropped area without any water restriction

Table1. Groundwater withdrawal through minor irrigation structures and additional groundwater available for irrigation during 2010-14 in the Tumaria canal command

Year	Net Recharge (ha-m)	Net Draft (ha-m)	Net Draft through minor irrigation structures (ha-m)	Net Draft other uses (ha-m)	% of Groundwater used for irrigation	0.9×R (AGW at semi-critical stage(ha-m)	Groundwater development stage (%)	Additional Water available for all purposes (ha-m)	Water Available for irrigation (ha-m)
2010	5271.62	3802.19	3470.20	331.99	91.27	4744.46	72.13	942.26	859.99
2011	4983.17	3802.30	3466.99	335.31	91.18	4484.85	76.30	682.55	622.36
2012	4659.04	3809.14	3470.61	338.53	91.11	4193.13	81.76	384.00	349.87
2013	4942.36	3515.91	3176.83	339.08	90.36	4448.13	71.14	932.21	842.31
2014	5234.85	4741.24	4386.57	354.67	92.52	4711.37	90.57	0.00	0.00
Average	5018.21	3934.16	3594.24	339.92	91.29	4516.39	78.38	588.20	536.96

Table2. Groundwater available under different % increase of additional water available for irrigation in TEC

SI. No.	% Increase	Increase in additional water available for irrigation (ha-m)	Available groundwater (ha-m)
1	0	0.00	3594.24
2	25	134.24	3728.48
3	50	268.48	3862.72
4	75	402.72	3996.96
5	100	536.96	4131.20

Table 3. Average monthly crop water demand, average canal water availability at field head, and groundwater demand of the TEC.

Month	Average Demand (ha-m)	Average Canal water availability at field head (ha-m)	GW Demand (ha-m)
January	639	142	497
February	884	93	791
March	1292	155	1137
April	806	116	690
May	984	228	756
June	897	70	827
July	533	209	324
August	685	202	483
September	1044	117	928
October	1749	75	1674
November	871	189	682
December	854	120	733
Total	11238	1716	9522

Table 4. Production function of different crops

Si. No.	crops	Production function
1	Wheat	$Y=32.5956-0.5232W+0.05618W^2-0.0005969W^3$
2	Paddy	$Y=13.0745+0.97203W-0.002663W^2$
3	*Masur*	$Y=-9.2465+1.55536W-0.02628W^2$
4	Potato	$Y=53.6520+2.8337W-0.0381W^2$
5	Pea	$Y=0+1.04558W-0.0074W^2$
6	*Urad*	$Y= 10.11+1.141W-0.035W^2+5\times10^{-5}W^3-3\times10^{-6}W^4$
7	Summer rice	$Y= -109.31+2.5498W-.0091W^2$
8	Soybean	$Y= 0+0.0414W+0.0161W^2-0.0001W^3$
9	Sugarcane	$Y= 154.81861EXP(0.0119003W)$
10	Mustard	$Y= 6.6519EXP(0.038495W)$
11	Maize	$Y= 100.7612EXP(-0.399397W)$

Note: Y= crop yield (Q/ha), W= net irrigation requirement (cm)

Table 5. Optimal crop Plan1 with NLP (without summer rice) with available canal and different levels of available groundwater

Plan-1 with NLP (Without summer Rice)					
Available groundwater corresponding to existing development stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	9545.60	Rice	0.00	Summer Rice	0.00
Masur	0.00	Maize	1.35	Sugarcane	1180.54
Pea	255.80	*Urad*	125.22	Other crops / Fallow land	12889.46
Mustard	114.92	Soybean	0.00	Total	14070.00
Sugarcane	1180.54	Sugarcane	1180.54		
Potato	72.59	Other crops / Fallow land	12762.88		
Other crops / Fallow land	2900.55	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**596.43**	
With 25% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	9545.60	Rice	0.00	Summer Rice	0.00
Masur	0.00	Maize	1.35	Sugarcane	1244.49
Pea	255.80	*Urad*	125.22	Other crops / Fallow land	12825.51
Mustard	114.92	Soybean	0.00	Total	14070.00
Sugarcane	1244.49	Sugarcane	1244.49		
Potato	72.59	Other crops / Fallow land	12698.93		
Other crops / Fallow land	2836.60	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**606.32**	

With 50% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	9545.60	Rice	0.00	Summer Rice	0.00
Masur	0.00	Maize	1.35	Sugarcane	1308.44
Pea	255.80	*Urad*	125.22	Other crops / Fallow land	12761.56
Mustard	114.92	Soybean	0.00	Total	14070.00
Sugarcane	1308.44	Sugarcane	1308.44		
Potato	72.59	Other crops / Fallow land	12634.98		
Other crops / Fallow land	2772.65	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**616.20**	
With 75% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	9545.60	Rice	0.00	Summer Rice	0.00
Masur	0.00	Maize	1.35	Sugarcane	1372.39
Pea	255.80	*Urad*	125.22	Other crops / Fallow land	12697.61
Mustard	114.92	Soybean	0.00	Total	14070.00
Sugarcane	1372.39	Sugarcane	1372.39		
Potato	72.59	Other crops / Fallow land	12571.03		
Other crops / Fallow land	2708.70	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**626.09**	
With 100% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	9545.60	Rice	0.00	Summer Rice	0.00
Masur	0.00	Maize	1.35	Sugarcane	1436.34
Pea	255.80	*Urad*	125.22	Other crops / Fallow land	12633.66
Mustard	114.92	Soybean	0.00	Total	14070.00
Sugarcane	1436.34	Sugarcane	1436.34		
Potato	72.59	Other crops / Fallow land	12507.08		
Other crops / Fallow land	2644.75	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**635.98**	

Table 6. Optimal crop Plan 2 with NLP (without summer rice) with available canal water and different levels of available groundwater

Plan-2 with NLP (Without summer Rice)					
Available groundwater corresponding to existing development stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12950.62	Rice	4062.02	Summer Rice	0.00
Masur	86.95	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13887.59
Mustard	226.63	Soybean	635.5014	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	72.59	Other crops / Fallow land	8919.09		
Other crops / Fallow land	0.00	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**652.36**	
With 25% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12951.06	Rice	3611.80	Summer Rice	0.00
Masur	86.51	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13887.59
Mustard	226.63	Soybean	635.50	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	72.59	Other crops / Fallow land	9369.31		
Other crops / Fallow land	0.00	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**665.90**	
With 50% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12950.47	Rice	4221.44	Summer Rice	0.00
Masur	87.09	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13887.59
Mustard	226.63	Soybean	635.50	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	72.59	Other crops / Fallow land	8759.67		
Other crops / Fallow land	0.00	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**679.59**	

With 75% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12950.17	Rice	4254.54	Summer Rice	0.00
Masur	87.39	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13887.59
Mustard	226.63	Soybean	635.50	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	72.59	Other crops / Fallow land	8726.57		
Other crops / Fallow land	0.00	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**693.82**	
With 100% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12949.90	Rice	4254.54	Summer Rice	0.00
Masur	87.67	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13887.59
Mustard	226.63	Soybean	635.50	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	72.59	Other crops / Fallow land	8726.57		
Other crops / Fallow land	0.00	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**708.36**	

was Rs. 912.57 Million as compared to the net return for Plan 2 with NLP (without summer rice) that was Rs. 708.36 Million obtained with 100% level of additional available groundwater. The decrease in net return form Plan 2 with NLP as compared to the return from existing crop was due to the fact that in case of existing crop plan no restrictions were imposed for the availability of water to crops.

Optimal crop Plan 2 with NLP (with summer rice) under available canal water and groundwater corresponding to existing groundwater development stage and different levels of additional available groundwater.

It can be observed from Table 7 that the area allocated to each crop was according to the minimum and the maximum area restrictions, imposed for different crops. On comparing the Plan 2 with NLP **(**without summer rice); with existing cropping pattern may be seen that the cropping area occupied by different crops except sugarcane had registered a change under plan 2. Wheat, *kharif* rice and sugarcane occupied the area as 12791.48 ha, 4063.40 ha and 182.41 ha under available groundwater, corresponding to existing development stage. The highest annual net return from crop Plan 2 with NLP **(**with summer rice) was Rs. 699.11 Million with 100% additional groundwater available for irrigation; as compared to the net return of existing cropped area plan, Rs. 912.57 Million. The reason for this decrease in net annual return, as compared to existing plan is same as explained in case of Plan 2 without summer rice.

Table 7. Optimal crop Plan2 with NLP (with summer rice) with available canal water and different levels of available groundwater

NLP Plan-2 (With summer rice)					
Available groundwater corresponding to existing development stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12791.48	Rice	4063.40	Summer Rice	109.76
Masur	92.87	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13777.84
Mustard	311.47	Soybean	635.50	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	81.23	Other crops / Fallow land	8917.71		
Other crops / Fallow land	59.74	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**641.25**	
With 25% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12950.77	Rice	3720.38	Summer Rice	109.76
Masur	86.80	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13777.84
Mustard	226.63	Soybean	635.50	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	72.59	Other crops / Fallow land	9260.73		
Other crops / Fallow land	0.00	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**657.50**	
With 50% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12950.91	Rice	3581.93	Summer Rice	109.76
Masur	86.66	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13777.84
Mustard	226.63	Soybean	635.50	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	72.59	Other crops / Fallow land	9399.19		
Other crops / Fallow land	0.00	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**670.93**	

With 75% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12950.39	Rice	4063.40	Summer Rice	109.76
Masur	87.18	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13777.84
Mustard	226.63	Soybean	635.50	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	72.59	Other crops / Fallow land	8917.71		
Other crops / Fallow land	0.00	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**684.80**	
With 100% of additional groundwater available corresponding to semi-critical stage					
***Rabi* season**		***Kharif* season**		***Zaid* season**	
Crop	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**	**Crop**	**Allocated area (ha)**
Wheat	12950.11	Rice	4063.40	Summer Rice	109.76
Masur	87.46	Maize	1.35	Sugarcane	182.41
Pea	550.80	*Urad*	269.63	Other crops / Fallow land	13777.84
Mustard	226.63	Soybean	635.50	Total	14070.00
Sugarcane	182.41	Sugarcane	182.41		
Potato	72.59	Other crops / Fallow land	8917.71		
Other crops / Fallow land	0.00	Total	14070.00		
Total	14070.00				
Net return (Rs. in millions)				**699.11**	

IV. CONCLUSION

The continuous increase in global population and simultaneous decrease in availability of water resources emphasize the need of conjunctive water use of surface-water and groundwater resources for irrigation. The problem of optimization of available land and water resources was solved using non-linear programming to obtain the net return in the Tumaria extension canal command area. The available seasonal canal water was very low in comparison to the demand of crops. The seasonal water demand of crops was very high which was not fulfilled by canal water only. So, there was pressure on groundwater. With the application of developed Plan 1 and Plan 2; maximum net return can be obtained with the fulfillment of food grain and fodder of the people in the command with no groundwater mining without its overexploitation. The net return from Plan 2 was higher as compared to the net return from Plan 1. The net return from crop Plan 2 (without summer rice) with 100 percent of additional available groundwater was found to be Rs. 708.36 Million while with summer rice the highest net return from Plan 2 was 699.11 Million. The optimal crop Plan 2 (without summer rice); wheat, *masur*, pea, mustard, sugarcane, potato, *kharif* rice, maize, *urad*, and soybean occupied 12949.90 ha, 87.67 ha, 550.80 ha, 226.63ha, 182.41ha, 72.59 ha, 4254.54 ha, 1.35 ha, 269.63 ha, and 635.50 ha, respectively with 100% of additional available groundwater. It is also concluded that such studies are useful for optimum crop planning with conjunctive use of canal and ground waters to get maximum return with the limited availability of water resources.

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