



International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS)

www.iasir.net

Optimization of land and water resource in Nakatiya Minor Canal command area in Udham Singh Nagar, Uttarakhand, India

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Abstract: With rapid urbanization and reduced water availability, the growing demand of food for large population can only be met by optimum utilization of available water and efficient allocation of available land to different crops. In this study a Linear Programming model was developed to maximize the net returns of the farmers considering, available land and water resources, crop water requirement and net return from different crops. The objective function of the model was subject to the following constraints: Water availability; Land availability, Crop area, and preference to grow a particular crop in a specific area. Based on three rainfall patterns i.e. normal, deficit and surplus the optimization was performed. Under deficit rainfall condition the optimized results of area allocation from the command was obtained as 20.66% kharif paddy, 17.95% soybean and 1.71% maize during Kharif followed by 24.17% wheat and 2.30% pea during Rabi season. For normal pattern the maximum return can be achieved through 27.75% area under kharif paddy, 70.38% under soybean, and 1.71% under maize during Kharif followed by 34.63% area under wheat and 2.30% area under pea. Likewise the net return can be maximized by growing summer paddy on 98.13% area during Kharif and wheat on 97.54% area during Rabi season.

Key words: Command area; cropping pattern; Crop water requirement; Linear Programming model.

I. Introduction

Land and water are two basic needs for progress in agriculture and economic development of any country. Both land and water are essential life supporting natural resources and they play a dominant role in agricultural production. Due to the increasing demand for food of the ever increasing human population, crop production per unit area needs to be increased and new areas with less favorable climatic conditions need to be cultivated. The introduction of irrigation schemes has improved agricultural production tremendously, but in spite of all efforts, areas covered by irrigation schemes are limited. Under these situations, it is necessary to do the best under the prevailing environmental conditions, in particular the seasonal water availability. This will need proper planning of the type and sequences of crops to be grown in a particular area for optimal overall production under rainfed condition. With continuing population growth and limited potential to increase suitable cropland, irrigation becomes an increasingly important tool to ensure sufficient global supply of food in the future. However increasing levels of irrigation will raise the cost of water and in some regions this may have severe consequences. As water scarcity increases, inefficient allocation of water will cause higher costs to the society. To fulfill the high demand for food, fiber and fuel of an ever increasing population, it is necessary to bring more area under cultivation or to increase production per unit area of available land and water resources. Bringing additional area under cultivation is difficult due to urbanization and a reluctance to disturb natural environments. Also, the allocation of water for irrigation will probably decrease from the present level of 90 % to 75-80 % over the next 10 to 15 years. Therefore, where demand of these natural resources for ever-increasing population outdoes the availability of these resources they need to be managed efficiently, optimally and sustainably. Keeping in view the need to find a better alternative solution of the problems especially faced by the farmers, an optimization model was formulated to maximize net income of farmers at different levels of water availability.

II. Materials and methods

The study was conducted for the command area of Nakatiya Minor under the Lower Bhakra Canal System located in Gadarpur Block of Udham Singh Nagar district of Uttarakhand state in India. Linear programming technique was used to allocate the available water optimally among different competing crop activities in the command area. The command area of Nakatiya Minor is 630 ha.

III. Collection of rainfall data

The rainfall data were collected for a period of 13 years (1999-2011) from the meteorological observatory located at the Crop Research Centre of G. B. Pant University of Agriculture and Technology, Pantnagar which was nearest to the study area. The daily rainfall data were converted into 52 standard meteorological weeks. In each year 7 days were counted in 52 meteorological weeks and in case of leap years 8 days were counted in 9th meteorological week.

These weekly rainfall data were used to classify the drought, normal and surplus rainfall weeks, using following criteria.

1. **Drought week:** - The week was classified as drought week in which rainfall received less than 50 percent of average rainfall.
2. **Surplus week:** - The week was classified as surplus week in which rainfall received more than twice of average monthly rainfall.
3. **Normal week:** - The week was classified as normal week in which rainfall received in between 50 percent and 200 percent of average weekly rainfall.

IV. Crops and cropping pattern

The study area falls in the semi arid zone, which being in Indo-Gangetic plane has fertile soils. The major crops grown by the farmers during *kharrif* season are paddy and wheat in *rabi* season. Besides these crops in *kharrif*, fodder crops and digger are also grown under irrigated conditions. The information regarding crops grown and area under different crops were obtained from District Agriculture Department and Subdivision of Irrigation Department, Rudrapur. The existing cropping patterns in the study area are shown in the **Table 1**.

Table 1. Existing cropping pattern in the study area

Khariff season		Rabi season	
crops	Percent area	crops	Percent area
Paddy	92.90	Wheat	86.98
Fodder crops	3.27	Fodder crops	0.43
sugarcane	0.156	Others	4.92
others	4.4	Potato	3.07

V. Water Resources

Besides rainfall, surface water supply from the Nakatiya Minor Canal system, and the ground water exploited through tubewells were the two important source of water in the command area. The daily canal 'stage level' data of Lower Bhakra were collected from Subdivision of Irrigation Department, Rudrapur. The surface water supply in the canal command area was limited. The minor command faces water deficit during Rabi season, due to low available flow of water in the Lower Bhakra Canal system. The Nakatiya Minor Canal command area was having a length of 6.1 km, designed capacity at the head of 0.53808 cumec and a total Culturable Command area of 630 ha.

VI. Irrigation requirement of crops

Net irrigation water requirements were calculated considering evapotranspiration, conveyance losses, application losses and effective rainfall. Rainfall, temperature, humidity, sunshine hours and wind velocity affect the evapotranspiration requirement of crops. Reference evapotranspiration was calculated using the following equation (**Doorenbos and Pruitt, 1977**).

$$ET_0 = K_p \times E_{pan} \quad (1)$$

where,

ET_0 = Reference crop evapotranspiration, mm/day

E_{pan} = Pan evaporation in mm/day and

K_p = Pan coefficient.

Crop evapotranspiration ET_{crop} (mm/day) was then calculated using the equation:

$$ET_{crop} = K_c ET_0 \quad (2)$$

where,

K_c is the crop coefficient.

Appropriate K_c values were selected for each crop which takes into account the crop characteristics, time of planting or sowing, stages of crop development and general climatic conditions (**Dorrenbos and Pruitt, 1977**). To account for the long duration of sowing crops in an area, the composite crop coefficient curves were prepared for calculating appropriate K_c values (**Singh et al., 1998**). The net irrigation requirement of all crops was calculated individually as follows:

$$IR = ET_{crop} - (Pe + Ge + Wb) \quad (3)$$

Where IR is the net irrigation requirement of crop (mm), Pe is the effective rainfall (mm), Ge is the ground water contribution (mm) and Wb is the stored soil water (mm).

The effective rainfall (also called dependable rainfall) was calculated according to USDA Soil Conservation Service Method. The formulae used in the analysis were as follows:

$$P_{eff} = P_t \left[\frac{125 - 0.2 \times P_t}{125} \right] \quad \text{for } P_t < 250 \text{ mm} \quad (4)$$

and

$$P_{eff} = 125 + 0.1 \times P_t \quad \text{for } P_t > 250 \text{ mm} \quad (5)$$

where

P_{eff} = Effective rainfall

P_t = Total rainfall

It was assumed that there was no contribution of ground water and there was no change in the value of stored soil water before and after the crop cultivation. The net irrigation requirement of the crop was estimated using the field water balance. The variables included where ET_{crop} , effective rainfall (P_{eff}), groundwater contribution (G_e) and stored soil water (W_b).

$$\begin{aligned} \text{So,} \quad NIWR &= ET_{crop} - (P_{eff} + G_e + W_b) \\ \text{where} \quad ET_{crop} &= \text{Crop evapotranspiration} \\ P_{eff} &= \text{Effective rainfall} \\ G_e &= \text{Groundwater contribution} \\ W_b &= \text{Stored soil water.} \end{aligned} \quad (6)$$

$$\text{Considering no change in } W_b \text{ before and after the crop duration and there is no contribution of groundwater.} \\ NIWR = ET_{crop} - P_e \quad (7)$$

VII. Area allocation model

The model used was a linear programming model consisting of three parts: (1) an objective function for maximization of net returns; (2) a set of constraints; and (3) a set of non negativity constraints. The model was formulated to allocate the land area between various crops in order to maximize the net return from the command area, subject to availability of water and land area limitations under different seasons of the year. The model was formulated as follows:

1. Objective function:

$$\begin{aligned} \text{Maximize} \quad Z &= \sum C_i X_i; \quad \text{for } i=1, 2, 3 \dots N \\ \text{where, } Z &= \text{total net returns from all the crops (Rs.)} \\ N &= \text{number of crops} \\ C_i &= \text{net return from } i^{\text{th}} \text{ crop (Rs./ha)} \\ X_i &= \text{crop area under } i^{\text{th}} \text{ crop (a decision variable).} \end{aligned} \quad (8)$$

The crop activities were *kharif paddy* (X1), *summer paddy* (X2), *wheat* (X3), *sugarcane* (X4), *lentil* (X5), *pea* (X6), *soybean* (X7) and *maize* (X8).

The objective function will be subjected to linearity and non-negativity constraints.

2. Linearity constraints:

i) Water availability constraints:

$$\begin{aligned} \sum W_{ij} X_i &\leq W_j; \quad i=1..N, \quad J=1,2 \dots M \\ \text{where, } W_{ij} &= \text{the water requirement for } i^{\text{th}} \text{ crop during } j^{\text{th}} \text{ season (mm),} \\ W_j &= \text{the total water available during } j^{\text{th}} \text{ season (ha-mm)} \end{aligned} \quad (9)$$

ii) Land area constraints:

$$\begin{aligned} \sum X_i &\leq A_j \\ \text{where, } A_j &= \text{the area available for cultivation in different seasons of a year:} \\ i &= \text{Crops in } kharif \text{ season (j=1);} \\ i &= \text{Crops in } rabi \text{ season (j=2)} \end{aligned} \quad (10)$$

iii) Crop area constraints:

$$\begin{aligned} E_i &\leq X_i \leq M_i \\ \text{where, } E_i &= \text{the existing area under the } i^{\text{th}} \text{ crop (ha)} \\ M_i &= \text{the maximum area which may be kept under cultivation of } i^{\text{th}} \text{ crop (ha)} \end{aligned} \quad (11)$$

iv) Non negativity constraints:

$$X_i \geq 0 \quad (12)$$

The non negativity constraints in respect of all the decision variables have been imposed so that all the decision variables appear at positive level.

VIII. Results and Discussion

The main crops grown in the command area are *kharif paddy*, *summer paddy*, *wheat*, *sugarcane*, *maize*, *soybean*, *pea* and *lentil*. The weekly gross irrigation water requirement for these crops was computed using Modified Pen-man method and considering the irrigation efficiencies. The gross water requirement estimated as 63.95 mm (*kharif paddy*), 987.1 mm (*summer paddy*), 157.2 mm (*wheat*), 768.4 mm (*sugarcane*), 80.7 mm (*lentil*), 112.7 mm (*pea*), and 15.04 mm (*maize*).

The optimal cropping patterns for Nakatiya Minor Canal command area under different rainfall patterns are shown in **Table 1**. *kharif paddy*, *wheat* and *soybean* are the three crops that decide the net returns from the command based on the rainfall pattern and available canal irrigation water. It is observed from the Table 1 that under normal rainfall conditions the area under *Kharif paddy* and *wheat* increased by 7% and 10%, respectively as compared to deficit rainfall conditions. An increase of about 53% in area under *soybean* was observed under normal rainfall conditions as compared to deficit rainfall situations. This is due to the lower water requirement

of soybean as compared to *kharif* paddy. The area left by *kharif* paddy and soybean under deficit rainfall pattern remained unoccupied. On comparing the optimal cropping pattern of surplus rainfall situation with other situations it was observed that there was a shift of *kharif* paddy to summer paddy, which was due to the high net return of the crop and sufficient water availability. The net return under surplus rainfall conditions further increased by about 6% through shifting from *kharif* paddy to summer paddy on the same area. The total net return from the Nakatiya Minor Canal command area under normal, deficit and surplus rainfall patterns are Rs. 1, 34, 42460, Rs. 83, 06,710 and Rs. 2, 98, 62,360 respectively.

Table 2: Optimal Cropping Pattern in Nakatiya Minor Canal Command under different rainfall patterns

Kharif Season			Rabi Season		
Crop	Area (ha)	Area (%)	Crop	Area (ha)	Area (%)
Normal Rainfall Pattern					
<i>Kharif</i> paddy	174.82	27.75	Wheat	218.16	34.63
Sugar cane	1.00	0.16	Sugarcane	1.00	0.16
Soybean	443.38	70.38	Pea	14.50	2.30
Maize	10.80	1.71	Lentil	0.00	0.00
Fallow	0.00	0.00	Fallow	396.33	62.91
Total	630.00	100.00		630.00	100.00
Deficit Rainfall Pattern					
<i>Kharif</i> paddy	130.17	20.66	Wheat	152.27	24.17
Sugar cane	1.00	0.16	Sugarcane	1.00	0.16
Soybean	113.10	17.95	Pea	14.50	2.30
Maize	10.80	1.71	Lentil	0.00	0.00
Fallow	374.92	59.52	Fallow	462.22	73.37
Total	630.00	100.00		630.00	100.00
Surplus Rainfall Pattern					
Summer paddy	618.20	98.13	Wheat	614.50	97.54
Sugar cane	1.00	0.16	Sugarcane	1.00	0.16
Soybean	0.00	0.00	Pea	14.50	2.30
Maize	10.80	1.71	Lentil	0.00	0.00
Fallow	0.00	0.00	Fallow	0.00	0.00
Total	630.00	100.00		630.00	100.00
Net Return from command (Rs.)					
Normal Rainfall			1,34,42,460		
Deficit Rainfall			83,06,710		
Surplus Rainfall			2,98,62,360		

IX. Conclusions

During the surplus rainfall pattern, *kharif* paddy was completely replaced by summer paddy because of higher return of the summer paddy as compared to *kharif* paddy and availability of water during March-April, from the surplus rains.

1. In the study area i.e. Nakatiya Minor Canal command area, *kharif* paddy, wheat and soybean are the crops that decide the net return from the command area based on the rainfall pattern and available canal irrigation water.
2. The optimal cropping pattern for maximum return under deficit rainfall condition from the command is 20.66% *kharif* paddy, 17.95% soybean and 1.71% maize during *Kharif* followed by 24.17% wheat and 2.30% pea during *Rabi* season.
3. Under normal rainfall conditions the maximum return can be achieved through 27.75% area under *kharif* paddy, 70.38% under soybean, and 1.71% under maize during *kharif* followed by 34.63% area under wheat and 2.30% area under pea.
4. Under surplus rainfall conditions, the net return can be maximized by growing summer paddy on 98.13% area during *kharif* and wheat on 97.54% area during *Rabi* season.

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