Optimization of Land and Water Resources in Nanakamatta Canal Command of Uttarakhand using Fuzzy Linear Programming

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Abstract *:The objective of this study is to develop fuzzy linear planning model for optimization of land and water resources in Nanakmatta canal command of Udham Singh Nagar district of Uttarakhand (India). The multi objective fuzzy linear programming (MOFLP) was applied for maximization of the crop sown area and net return (NR). The linear membership functions were developed from the linear programming (LP) results and objectives were fuzzified over the tolerance range.The significant increase in the value of level of satisfaction (λ) was found from 0.5525 to 0.5825 by using the MOFLP model based on maximum approach. Fuzzy Linear Programming (FLP) solution yields a net benefit of 84.61 million rupees against net sown area of 1856.40 ha under normal rainfall with a satisfaction level (λ) of 0.5855 and 75.98 million rupees against net sown area of 1627.90 ha under 50% probability rainfall condition with a satisfaction level (λ) of 0.5525.*

Keywords:*optimization, maximization, multi-objective, Fuzzy Linear Programming*

I. Introduction

Day by day the world's population is increasing at an alarming rate resulting in increasing demand of food and fiber. On the other hand, per capita land and water resources are decreasing at alarming rate. Water is valuable natural resource, which is used for agriculture, recreation and industrial purpose [1]. Due to industrialization and population growth the demand and utilization of water is increased which resulted in increased pressure on the water resources. The major portion of the water resource is used in agriculture sector for irrigation purpose to enhance the crop production. Due to growing demand for domestic and industrial purpose the share of the irrigation water is diverted for industries, recreation and drinking purpose. Therefore, it is need of the time to utilize the available water resources optimally and judiciously.

Optimization techniques provide a powerful tool for analysis of problems that are formulated with single quantifiable objectives. However, the real-world decision- making problems usually require consideration of multiple, conflicting and non- commensurable criteria. The decision problems like crop area planning involve multi-criteria decision making, where the decision maker generally follows a satisfying solution rather than the maximization objectives [2].Many single as well as multiple objective crop area allocation models were developed in the past [3], [4], [5], [6], [7].

In the last three decades, multiple objective linear programming techniques have observed magnificent growth [8], [9], [10], [11]. Though, many water resources, crop planning and canal command area planning research work have not utilized the multi-objective linear programming

throughout the entire research of the planning process. There are different reasons behind this. Some multi-criteria methods require information that is difficult to obtain in real-world surroundings. Thus there is a need to use linear fuzzy programming techniques for their simplicity in computation and flexibility in implementation. In this study the goal was maximization of net benefit and maximization of cropped area under the available of land and water resources. Multi-objective programming techniques allow to satisfy these conflicting objectives. Many researchers used fuzzy programming technique in the past mainly for land and water resources management [9], [11], [12], [13].

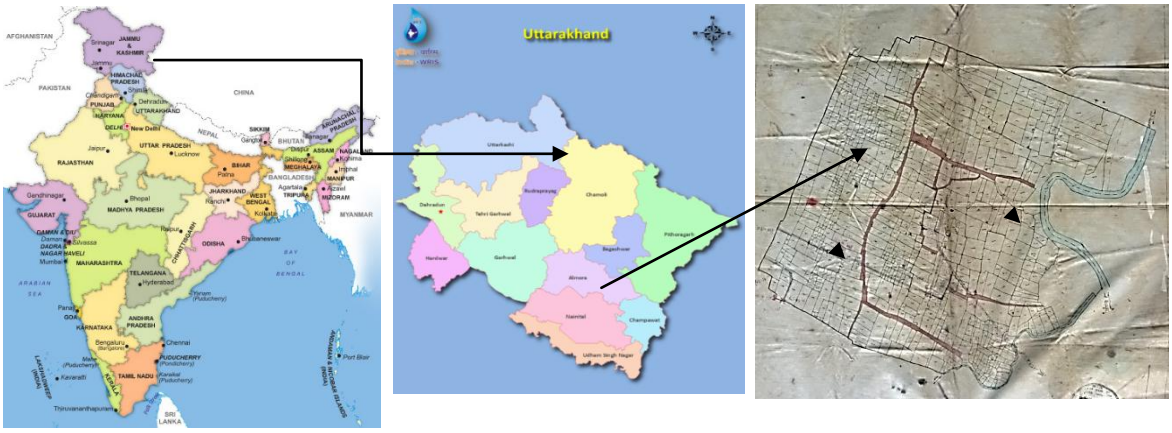
The multi-objective techniques used in the study were Linear Fuzzy Programming under different rainfall conditions. In this study canal surface water and total permissible annual ground water draft was taken equal to the recharge from the rainfall in the command under different rainfall patterns. There were two objective functions benefit maximization and maximization of cropped area.

The *Tarai* region of the Uttarakhand state of India is of moderate climate and the main occupation of the inhabitation of this region is agriculture. Almost 75% population of this region is dependent on agriculture for their livelihood. Rice, wheat, maize, and some of the pulses are the main crops grown by the farmers of this region. These products not only feed the inhabitation of this region but some of the rice, wheat and pulses are sent to the other parts of the country. The area is bestowed with plenty of water resources and large flat agricultural land and therefore, the optimal planning for land and water resources is necessary to check the misuse.

II. Materials and Methods

The study was under taken in the Nanakmatta canal command located in Sitarganj *Tahsil* of Udham Singh Nagar district which is located between 28º 45' N to 29º 23'N latitude and laterally extends between 78º 45' E to 80 º 08' longitudes. The Nanakmatta canal originates from Nanak Sagar dam located about 12 km away from the *tahsil* head quarter. The head discharge of the canal was4.773 (58 cusec). Total length of canal is 13.64 km. The total Cultural Command Area (CCA) was 1236 ha. Agriculture practices in the Nanakmatta canal command area revolve around two main seasons namely *Kharif* and *Rabi*. The sowing in the *Kharif* season (summer crops) begins generally with the onset of southwest monsoon in mid June, while the *Rabi* season (winter crops) starts with beginning of cold weather i.e., by the end of the month of October or early November. The important crop grown in *Kharif*season is rice and that in the *Rabi* season is wheat.The index map of the study areais shown in Figure 1.

Figure 1. Index map of Nanakmatta canal command.



Linear programming model

The two objective functions being considered, under present study were maximization of crop area and net benefits. Mathematical linear modeling with two objectives with the linear constraints is explained in below.

Model description

i) ***Maximization of net return*:** Considering the economic objective of net benefit maximization is commonly considered in the planning area problems and farmers often prefer cropping patterns which can provide more benefits. So mathematically, it can be formulated as:

$$\text{Max } Z_1 = \sum_{j=1}^{2} \sum_{i=1}^{n} R_i X_i^j \quad i=1\ldots\ldots n,\ j=1,\ 2 \qquad \ldots (1)$$

where, R_i = Net return from the ith crop activity (Rs/ha), X_i^j = area under crop activity i during season j (i=1 for paddy, i=2 for wheat, i=3 for sugar cane, i=4 for barseem, i=5 for maize, i=6 for potato and i=7 for cowpea); j = 1 for *Rabi* and 2 for *Kharif* season.

ii) ***Maximization of cropped area*:** Considering the utility of irrigated agriculture over the rainfed one, the cropped area maximization objective has been introduced in the model formulation. It can be written mathematically as follows:

$$\text{Max } Z_2 = \sum_{j=1}^{2} \sum_{i=1}^{n} X_i^j \qquad i=1\ldots\ldots n,\ j=1\ldots.2 \qquad \ldots (2)$$

where, X_i^j area (ha) under the crop activity i during season j.

Model Constraints:

The model was subjected to the following constraints:

i) ***Water requirement:*** The irrigation water demand of all the crops in any month should utmost equal to the total water available.

$$\sum_{i=1}^{n} W_i^k \ X_i^j \le \mathrm{CW}^k + GW^k \qquad i=1\ldots n,\ j=1,2\ k=1\ldots.12 \qquad \ldots(3)$$

where, W_i^k is the total irrigation water used for production of crop i (ha-cm) during month k, CW^k and GW^k are the canal water availability at field (= canal water availability at head x conveyance efficiency) and ground water availability during month k. (k = 1 for January to 12 for December). The conveyance efficiency of the canal system has been taken as 60 percent.

ii) ***Annual groundwater extraction constraint*:** The total groundwater use should not exceed the annual allowable groundwater extraction:

$$\sum_{k=1}^{12} GW^k \le AGW \qquad k=1\ldots..12 \qquad \ldots (4)$$

where AGW is the allowable annual groundwater extraction (ha-cm) in the command.

iii) ***Total cultivable land constraint*:** The land allocated to different crops in any month should not exceed the total cultivable area in the command.

$$\sum_{i=1}^{n} X_i^j \leq A_k \qquad i=1....n,\ j=1,2\ k=1.....12 \qquad ...(5)$$

Where A_k is the total cultivable area available during j^{th} season in the command (ha) and X_i^j is the area under i^{th} crop during j^{th} season (ha).

iv) ***Affinity Constraints*:** The area allocated to a crop should be less than the maximum area allotted for that crop in the command area.

$$X_i^j \leq A_i^j{}_{\max} \qquad i = 1....n,\ j=1,2 \qquad ...(6)$$

v) ***Non-negativity constraints***: This restriction states that all decision variables of model should be non-negative.

$$X_i^j \geq 0 \text{ and } GW^k \geq 0 \qquad ...(7)$$

Multi-objective Fuzzy Linear Programming Model

The fuzzy objective function is characterized by its membership function, which plays as substitute characterization of preference in determining the preferred outcome for each of the objectives. Membership function for the tth objective denoted by [μZ(x)] and should have the following conditions:

$$\mu Z(x) = \begin{cases} 1 & \text{if } Z_t(x) \geq Z_t^* \\ 0 \leq \mu Z(x) \leq 1 & \text{if } Z_t^m \leq Z_t(x) \leq Z_t^* \\ 0 & \text{if } Z_t(x) \leq Z_t^m \end{cases} \qquad ...(8)$$

In the present problem, a linear membership function has been used and thus the equation 8 changes to

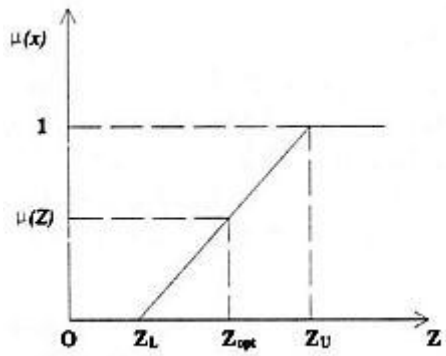
$$\mu_i(x) = \begin{cases} 1 & \text{if } Z > Z_U \\ \dfrac{Z - Z_L}{Z_U - Z_L} & \text{if } Z_L \leq Z \leq Z_U \\ 0 & \text{if } Z \leq Z_L \end{cases} \qquad ...(9)$$

where,

Z_L = lowest acceptable level of objective function; and Z_U = maximum level of objective function.

The linear membership functions for objective Z is presented in Fig 2.

Figure 2. Linear membership function for objective Z



The $\mu_i(x)$ reflects the degree of achievement and its value will be "1" for perfect achievement and "0" for no-achievement (worst achievement) of a given strategy and some intermediate values otherwise. The model can be transformed as follows:

$$\text{Max}_{x \geq 0 \text{ mini}} \frac{Z - Z_L}{Z_U - Z_L} \quad \text{... (10)}$$

subjected to the constraints

$A X \leq B$

$X \geq 0$

where, A is technological coefficient matrix of m x n and B is the column vector generally for resource of the order (m x 1).

Introducing new variable λ, the Fuzzy Linear Program can be formulated as equivalent Linear Program model with objective function Max λ, subject to

$\frac{Z - Z_L}{Z_U - Z_L} \geq \lambda$ for each objective function

$A X \leq B$

$0 \leq \lambda \leq 1$ and $X \geq 0$

The solution of above formulated Fuzzy Linear Programming model was solved by following steps:

1. The problem was considered as a linear programming model by taking one objective at a time.
2. From step 1, corresponding values of each objective was determined for each derived solution.
3. From step 2, best (Z_U) and worst (Z_L) values for each objective was calculated.
4. The linear membership function were formulated for each objective functions.
5. The equivalent Linear Programming model for the fuzzy objective problem was formulated as defined above.
6. The compromise solution along with degree of truth (λ) was determined by solving the fuzzified linear programming model with the help of LINGO.

The overall schematic diagram of solving the fuzzy linear programming model is shown in Fig 3

III. Result and Discussions

Multi objective fuzzy linear programming (MOFLP) problem considers fuzzy input data by fuzzy membership functions. The assumption of the method is that, the objectives and constraints are in an imprecise and uncertain situation can be represented by fuzzy sets. The fuzzy objective function can be maximized or minimized. In fuzzy linear programming the fuzziness of available resources are characterized by the membership function over tolerance range. In the present study MOFLP model is developed and applied for the Nanakmatta canal command. The two objectives under considerations are Net Return (NR) and maximize crop area respectively for under normal rainfall condition and 50 percent probability rainfall condition.

Initially in MOFLP model the fuzziness is considered only in the objective function and the constraints are crisp in nature. The MOFLP model is solved as per the procedure given in the methodology. These objective functions are maximized separately subjected to constraints (Eqs. 1–7) using the LINGO (Language for Interactive General Optimization). The results of this individual maximization of the two different objectives are used to develop the membership function for each objective taking the help of the best/upper $Z_U(+)$ and worst/lower $Z_L(-)$ value of the same. The best/upper and worst/lower values of the objective function after comparison under normal rainfall condition is presented in Table 1.

Figure 3. Schematic diagram of solving fuzzy linear programming

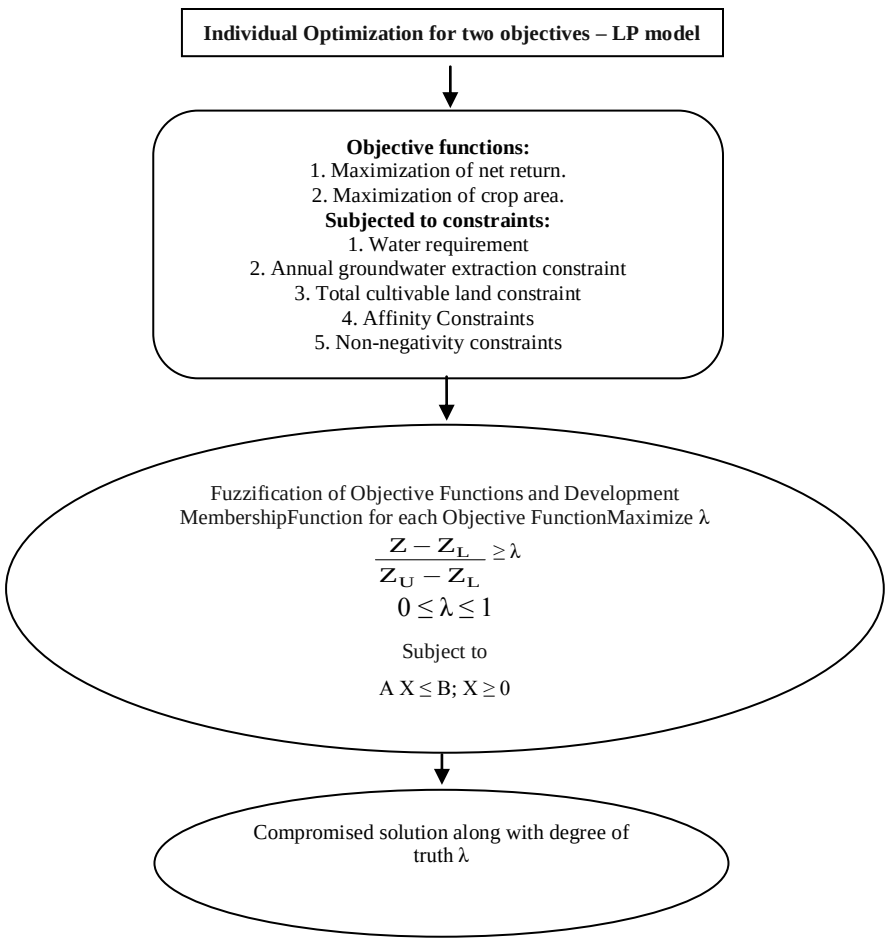


Table 1Best/upper and worst/lower values of the objective function after comparison under normal rainfall condition.

Objective function (Z)	Maximize net return (Rs)	Maximize crop area (ha)
Z_U	85785500.00	1946.70
Z_L	82962601.72	1728.90

The optimal resource utilization plan for maximization of net return from the crop activities and maximization of land use under normal rainfall conditions for the Nanakmatta canal command system is shown in Table 2.

Table 2 Optimal cropping pattern under normal rainfall condition in the Nanakmatta canal command system

***Kharif* season (July – October)**		***Rabi* season (October – March)**	
Crop	**Area(ha)**	**Crop**	**Area(ha)**
Paddy	698.66	Wheat	540.39
Sugarcane	15.00	Sugarcane	15.00
Maize	100.00	*Barseem*	80.00
Cowpea	45.00	Potato	377.34
Potato (season overlapping)	377.34	Uncropped	223.27
Total	**1236.00**	**Total**	**1236.00**
Total groundwater used (ha-cm)			**28798.80**
Total canal water used (ha-cm)			**64966.37**
Surplus canal water (ha-cm)			**101523.10**
Annual net return from the command (Rs.)			**84615170.00**
Total sown area (ha)			**1856.40**

It was observed from Table 2 that paddy during *Kharif* season and wheat during *Rabi* season occupies maximum area but slightly lower than that under existing cropping pattern. This reduction in the area of paddy and wheat is due to the reduced availability of ground water that was restricted to be within the safe limit of ground water development stage. The area under potato crop has increased drastically because of higher return as compared to that of wheat and early planting (month of October). The area under other crops was within the specified limits superimposed in the model. The fuzzified optimal plan resulted in annual return of Rs. 84.615 millionagainst net sown area of 1856.40 ha. A total of 101523.10ha-cm of canal flow remained unutilized during low demand months, therefore, more area could be brought under sowing through re-scheduling of canal water flows during higher water demanding months. This will not only increase the net return but also increase the net sown area in the command and will reduce burden over the ground water draft.

Table 3 Best/upper and worst/lower values of the objective function after comparison under 50 percent probability rainfall condition.

Objective function (Z)	Maximize net return (Rs.)	Maximize crop area (ha)
Z_U	77853370.00	1746.60
Z_L	73670486.36	1481.40

The optimal resource utilization plan for maximization of net return from the crop activities and maximization of land use under 50 percent probability rainfall conditions for the Nanakmatta canal command system is shown in Table 4.

It may be observed from Table 4 that paddy during *Kharif* season and wheat during *Rabi* season occupies the maximum area but the wheat area during *Rabi* season reduced drastically due to increased irrigation demand owing to lesser rainfall received at 50 percent probability. The land left by wheat remained uncropped due to restricted and lower ground water availability because of lower recharge of aquifer. The area under potato crop has also decreased as compared to that under normal rainfall conditions (Table 2) because of lower water availability and higher irrigation demand. The area under other crops was within specified limits superimposed in the model. The fuzzified optimal plan resulted in annual return of Rs. 75.981 millionagainst net sown area of 1627.90 ha. A total of 75338.16 ha-cm of canal flow remained unutilized during low demand months, therefore, more area could be brought under sowing through re-scheduling of canal water flows during higher water demanding months. This will not only increase the net return but will also increase net sown area in the command and reduced burden over the ground water draft.

Table 4 Optimal cropping pattern under 50 percent probability rainfall condition in the Nanakmatta canal system command

***Kharif* season (July – October)**		***Rabi* season (October – March)**	
Crop	**Area(ha)**	**Crop**	**Area(ha)**
Paddy	600.90	Wheat	311.94
Sugarcane	15.00	Sugarcane	15.00
Maize	100.00	*Barseem*	80.00
Cowpea	45.00	Potato	475.10
Potato (season overlapping)	475.10	uncropped	353.96
Total	**1236.00**	**Total**	**1236.00**
		Total groundwater used (ha-cm)	**28106.64**
		Total canal water used (ha-cm)	**91151.31**
		Surplus canal water (ha-cm)	**75338.16**
		Annual net return from the command (Rs.)	**75981111.00**
		Total sown area (ha)	**1627.90**

IV. Conclusions

The MOFLP model was developed and applied for the Nanakamatta canal command in U.S.Nagar Uttarakhand, India. Based on the study following conclusion were drawn:

a) Under normal rainfall conditions, the fuzzified optimal plan, resulted in annual return of Rs. 84.615 million against net sown area of 1856.40 ha for optimized value λ=0.5855. A total of 101523.10 ha-cm of canal flow remained unutilized during low demand months (July, August and September) however, the groundwater was completely utilized with maximum use during month of October.

b) The fuzzified optimal plan, under 50 percent probability rainfall, resulted in annual return of Rs. 75.981 million against net sown area of 1627.90 ha at optimized value of λ=0.5525. A total of 75338.16 ha-cm of canal flow remained unutilized during low demand months which indicated that more than 25 percent canal water was consumed to cater irrigation water demand as compared to that under normal rainfall conditions.

c) More area could be brought under sowing through re-scheduling of canal water flows during higher water demanding months namely February, March, October and November. This will not

only increase the net return but will also increase the net sown area in the command and reduced burden over the groundwater draft.

V. References

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