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Optimal Irrigation Planning and Operation of Multi Objective Reservoir Using Fuzzy Logic

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Abstract

In the present study the MOFLP models have been developed for the optimal cropping pattern planning which maximizes the four objectives such as Net Benefits (NB), Crop Production (CP), Employment Generation (EG) and Manure Utilization (MU) under conflicting situation and also, for maximization of Releases for Irrigation (RI) and Releases for Power (RP) simultaneously under uncertainty by considering the fuzziness in the objective functions. The developed models have been applied using the LINGO 13 (Language for Interactive General Optimization) optimization software to the case study of the Jayakwadi Project Stage-II across Sindhphana River, in the State of Maharashtra India. The various constraints have been taken into consideration like sowing area, affinity to crop, labour availability, manure availability, water availability for optimal cropping pattern planning. Similarly constraints to find the optimal reservoir operating policy are releases for power and turbine capacity, irrigation demand, reservoir storage capacity, reservoir storage continuity. The level of satisfaction for a compromised solution of optimal cropping pattern planning for four conflicting objectives under fuzzy environment is worked out to be λ = 0.68. The MOFLP compromised solution provides NB = 1088.46 (Million Rupees), CP = 241003 (Tons), EG = 23.13 (Million Man days) and MU = 111454.70 (Tons) respectively. The compromised solution for optimal operation of multi objective reservoir yields the level of satisfaction (λ) = 0.533 for maximizing the releases for irrigation and power simultaneously by satisfying the constraint of the system under consideration. The compromised solution provides the optimal releases, $i.e.$ RI = 348.670 Mm³ and RP = 234.285 Mm³ respectively.

Keywords

1. Introduction

Irrigation planning objectives associated with uncertainty are conflicting and especially in developing countries like India, there are many objectives related to irrigation planning and reservoir operation that must simultaneously be satisfied. Therefore, irrigation planning with uncertainty to find optimal cropping patterns and to derive the optimal releases of reservoir operation, has thus studied in multi objective framework under fuzzy environment so that suitable and sustainable strategies can be developed for practical implementation.

The LP irrigation planning model has been developed for evaluation of irrigation development strategy for the case study of the Sri Ram Sagar project in the State of Andhra Pradesh, India. The uncertainty in inflows arising out of the uncertainty in the rainfall is tackled through chance constrained (stochastic) programming [1]. Raju and Nagesh Kumar [2] formulated the Fuzzy Linear Programming (FLP) for three conflicting objectives and dealt with fuzzification of objective functions. Raju and Duckstein [3] developed the MOFLP model for sustainable irrigation planning, considering only the objectives fuzzy in nature. Regulwar and Anand Raj [4] developed a monthly Multi Objective Genetic Algorithm Fuzzy Optimization model and it has applied to a multi-reservoir system in the Godavari river sub basin in the State of Maharashtra, India. Regulwar and Kamodkar [5] have focused on the derivation of multipurpose single reservoir release policies with fuzzy constraints. Regulwar and Gurav [6]-[10] and Gurav and Regulwar [11] [12] have presented the irrigation planning under uncertainty using multi objective fuzzy linear programming approach. Kamodkar and Regulwar [13]-[15] have presented the study of multiobjective single reservoir operation model focused with the uncertainty associated with releases for irrigation and hydropower and applied same to the Jayakwadi project stage-II in the State of Maharashtra, India.

In the literature presented, it has found that the no model has been formulated for the multi objective sustainable irrigation planning and reservoir operation with Fuzzification of the objective functions to the case study of the Jayakwadi reservoir project stage-II. The objectives of the present study are to develop the model for optimal cropping pattern planning under fuzzy environment and also to develop model for optimal operating policies in a multiple crop, multiple criterion environment, on a reservoir in a river sub basin.

2. Methodology and Model Development

2.1. Description of the Case Study Area

The salient features of the Jayakwadi Project Stage-II have shown in the following **Table 1**. **Figure 1** shows an index map of Jayakwadi project, State of Maharashtra, India.

2.2. Model Development for Cropping Pattern Planning

The objective is to find out the optimal cropping pattern for 75% dependable yield in command area. The problem has been formulated as an optimization model based on deterministic inflows.

2.3. Objective Function

The following four objectives for irrigation planning have been considered in the present study.

Table 1. Salient features of the Jayakwadi project stage-II.

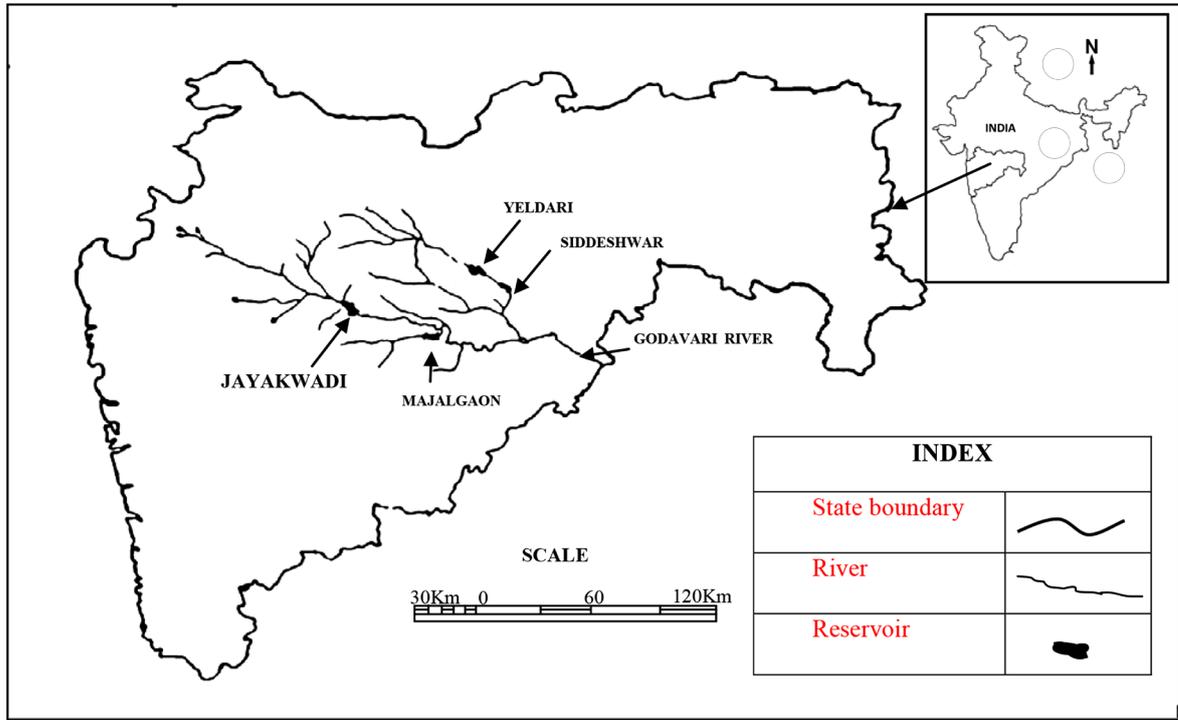| Sr. No.	Particular	Quantity
1	Gross Capacity at F. R. L.	453.64 Mm^3
2	Capacity of Dead Storage	142.34 Mm^3
3	Capacity of Live Storage	311.30 Mm^3
4	Capacity for Power Generation	2.25 MW
5	No. of Turbines	3×750 KW
6	Irrigable Command Area	938.85 Km^2

Figure 1. Index map of Jayakwadi project, state of Maharashtra, India.

2.4. Maximization of Net Benefits (NB)

Maximization of Net benefits can be expressed as:

$$\text{Maximize } NB = \left[\left(\sum_{i=1}^{K_1} A_i^K + \sum_{i=1}^{R_1} A_i^R + \sum_{i=1}^{T_1} A_i^{TS} + \sum_{i=1}^{P_1} A_i^P + \sum_{i=1}^{H_1} A_i^{HW} \right) BC_i \right.$$
$$\left. - \left(\sum_{i=1}^{K_1} A_i^K + \sum_{i=1}^{R_1} A_i^R + \sum_{i=1}^{T_1} A_i^{TS} + \sum_{i=1}^{P_1} A_i^P + \sum_{i=1}^{H_1} A_i^{HW} \right) IC_i \right] \tag{1}$$

[In which i = crop index. 1 = Sugarcane (P), 2 = Banana (P), 3 = Chilies (TS), 4 = L S Cotton (TS), 5 = Sorghum (K), 6 = Paddy (K), 7 = Sorghum (R), 8 = Wheat (R), 9 = Gram (R) and 10 = Groundnut (HW) and ha = 10000 m²]

A_i^K = Area of ith crop in kharif season (ha); A_i^R = Area of ith crop in rabi season (ha);
A_i^{TS} = Area under two seasonal crops in (ha); A_i^P = Area under perennial crop in (ha);
A_i^{HW} = Area under hot weather crop in (ha); BC_i = Benefit coefficient for i^{th} Crop;
IC_i = Input cost for i^{th} Crop; P = Perennial;
P_1 = Perennial crops; TS = Two seasonal;
T_1 = Two seasonal crops; K = Kharif;
K_1 = Crops under Kharif season; R = Rabi;
R_1 = Crops under Rabi season; HW = Hot weather;
H_1 = Hot weather crops.

The Net Benefits coefficients (NB) from the irrigated area under various crops are obtained by subtracting the input cost (20% of gross benefit) from gross benefit for different crops. The Gross benefits are calculated by multiplying the average yield of a crop per ha and current market price of that crop. The Crop Production (CP) coefficients are taken as the average yield of a crop per ha [16].

2.5. Maximization of Crop Production (CP)

The crop production is maximized and can be expressed as:

$$\text{Maximize } (CP) = \left[\left(\sum_{i=1}^{K_1} A_i^K + \sum_{i=1}^{R_1} A_i^R + \sum_{i=1}^{T_1} A_i^{TS} + \sum_{i=1}^{P_1} A_i^P + \sum_{i=1}^{H_1} A_i^{HW} \right) AY_i \right] \tag{2}$$

AY_i = Average yield of ith crop.

2.6. Maximization of Employment Generation (EG)

Keeping in mind the socioeconomic development, the policy maker has to concentrate on the maximization of employment generation or labour availability.

$$\text{Maximize } (EG) = \left[\left(\sum_{i=1}^{K_1} A_i^K + \sum_{i=1}^{R_1} A_i^R + \sum_{i=1}^{T_1} A_i^{TS} + \sum_{i=1}^{P_1} A_i^P + \sum_{i=1}^{H_1} A_i^{HW} \right) MD_i \right] \tag{3}$$

MD_i = Number of man days for i^{th} crop per ha.

The requirement of labour or numbers of Man Days (MD) for a particular crop per ha is considered through discussion with farmers and experts from agricultural fields.

2.7. Maximization of Manure Utilization (MU)

In order to maintain the fertility and nutrient sufficiency of soil in a proper manner, one should concentrate on the maximization of the use of manures.

$$\text{Maximize } (MU) = \left[\left(\sum_{i=1}^{K_1} A_i^K + \sum_{i=1}^{R_1} A_i^R + \sum_{i=1}^{T_1} A_i^{TS} + \sum_{i=1}^{P_1} A_i^P + \sum_{i=1}^{H_1} A_i^{HW} \right) MU_i \right] \tag{4}$$

MU_i = Requirement/Utilization of manure in tons for i^{th} crop per ha.

The Requirement of Manure (MU) for a crop per ha is considered through discussion with farmers and experts from agricultural fields.

2.8. Constraints

The above four objectives are subject to the various constraints like total sowing area, maximum sowing area, affinity to particular crops, labour availability, manure availability, water availability and non-negativity (The details are not given due to space limitation).

2.9. Model Development for Reservoir Operation

The two objective functions are considered for the present case study, which are:
  1) Maximization of irrigation releases (*i.e.* RI)

$$\text{Maximize } z = \sum_{t=1}^{12} (RI)_{it} \tag{5}$$

  2) Maximization of hydropower releases (*i.e.* RP)

$$\text{Maximize } z = \sum_{t=1}^{12} (RP)_{it} \tag{6}$$

2.10. Constraints

The above two objectives are subject to the various constraints like Releases for Power, Turbine Capacity, Irrigation Demand, Reservoir Storage-Capacity, and Reservoir Storage Continuity Constraint (The details are not given due to space limitation).

2.11. Algorithm for Fuzzy Linear Programming with Fuzzy Objective Functions ($\tilde{Z}$)

The Fuzzy Linear Programming (FLP) Algorithm for fuzzy objectives has divided into the following steps:
  1) Considering only one objective at a time and solve the problem as a linear programming problem.

2) Focusing on the results obtained in the step 1, work out the corresponding values of each objective from the solution obtained.

3) Comparing the values of objective function obtained in step 2; find out (Z_U) and (Z_L) for each objective under consideration.

4) Keeping in view the values of (Z_U) and (Z_L) for each objective; establish the linear membership function.

5) Introducing the dummy variable (λ), now the objective function changes to maximize the dummy variable (λ) subjected to the additional constraints due to the fuzziness in the value of the objective functions and original constraints.

6) Develop the equivalent Linear Programming (LP) model as a Multi Objective Fuzzy Linear Programming (MOFLP) model.

7) Work out compromised solution with the level of satisfaction (λ).

2.12. Fuzzy Linear Programming

The most general type of fuzzy linear programming is formulated as follows:

$$\max \sum_{j=1}^{n} C_j X_j$$

$$\text{S.t.} \sum_{j=1}^{n} A_{ij} X_j \leq B_i \qquad \left(i \in \mathbb{N}_m \right)$$

$$X_j \geq 0 \qquad \left(j \in \mathbb{N}_n \right)$$

where A_{ij}, B_i, C_j are fuzzy numbers, and X_j are variables whose states are fuzzy numbers $\left(i \in \mathbb{N}_m, j \in \mathbb{N}_n \right)$; the operations of addition and multiplication are operations of fuzzy arithmetic, and $\leq$ denotes the ordering of fuzzy numbers [17].

3. Results and Discussion

In the present study the MOFLP models have been developed for the optimal cropping pattern planning which maximizes the four objectives such as NB, CP, EG and MU under conflicting situation and also, for maximization of RI and RP simultaneously under uncertainty by considering the fuzziness in the objective functions. The developed models have been applied to the case study of the Jayakwadi project stage-II across the Sindhphana River near Majalgaon town.

The objective functions of the present study considering the Equations (1)-(4) of the Linear Programming Planning (LPP) model, which are the maximization of the NB, CP, EG and MU for the command area of the Jayakwadi Project Stage-II. These objective functions are maximized separately subjected to constraints using the LINGO 13 (Language for INteractive General Optimization) optimization software. The results of this individual maximization of the four different objectives are used to construct the linear membership function for each objective taking the help of the best (+) and worst (−) value of the same. The membership functions are shown graphically in **Figures 2-5**.

The same membership functions are written in the form of mathematical Equations (7)-(10).

$$\mu_{z_1}(x) = \begin{cases} 1 & z_1 \geq 1180.33 \\ \dfrac{(z_1 - 892.76)}{(1180.33 - 892.76)} & 892.76 < z_1 < 1180.33 \\ 0 & z_1 \leq 892.76 \end{cases} \tag{7}$$

$$\mu_{z_2}(x) = \begin{cases} 1 & z_2 \geq 315610.80 \\ \dfrac{(z_2 - 77762.07)}{(315610.80 - 77762.07)} & 77762.07 < z_2 < 315610.80 \\ 0 & z_2 \leq 77762.07 \end{cases} \tag{8}$$
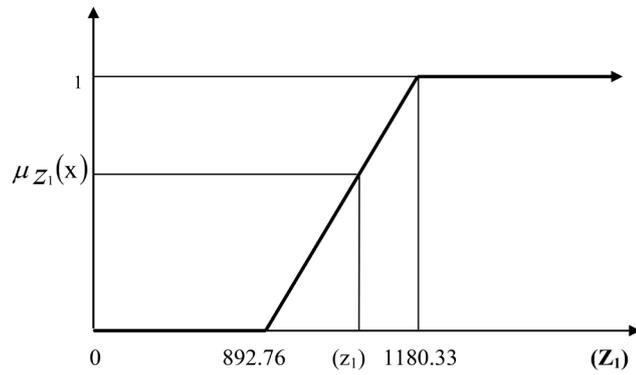
Figure 2. Membership function for Z_1 (Million rupees).
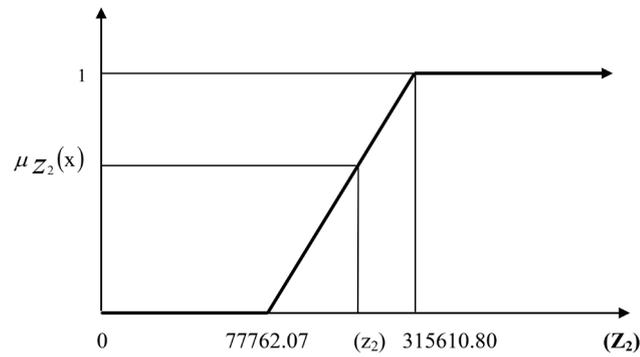

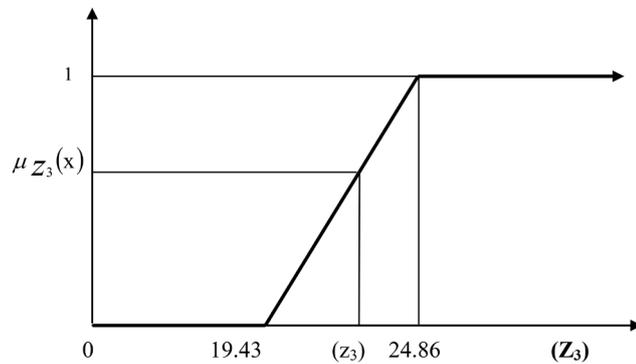**Figure 3.** Membership function for Z_2 (Tons).

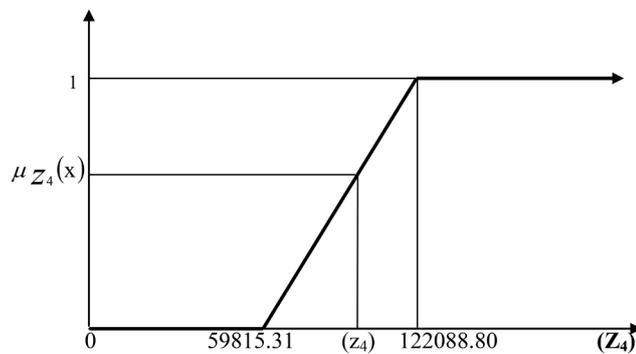**Figure 4.** Membership function for Z_3 (Million man days).

Figure 5. Membership function for Z_4 (Tons).

$$\mu_{z_3}(x) = \begin{cases} 1 & z_3 \geq 24.86 \\ \dfrac{(z_3 - 19.43)}{(24.86 - 19.43)} & 19.43 < z_3 < 24.86 \\ 0 & z_3 \leq 19.43 \end{cases} \tag{9}$$

$$\mu_{z_4}(x) = \begin{cases} 1 & z_4 \geq 122088.80 \\ \dfrac{(z_4 - 59815.31)}{(122088.80 - 59815.31)} & 59815.31 < z_4 < 122088.80 \\ 0 & z_4 \leq 59815.31 \end{cases} \tag{10}$$

The results are shown in **Table 2**. The membership functions $\mu_1(X)$, $\mu_2(X)$, $\mu_3(X)$ and $\mu_4(X)$ of the fuzzy sets characterizing the objective functions rise linearly from 0 to 1 at the highest achievable value of $Z_1 = 1180.33$ Million Rs, $Z_2 = 315610.80$ Tons, $Z_3 = 24.86$ Million Man days and $Z_4 = 122088.80$ Tons respectively. The level of satisfaction associated with NB rises from 0 if the NB is 892.76 Million Rs or less to 1 if the total NB is $Z_1 = 1180.33$ Million Rs or more. The level of satisfaction with respect to CP rises from 0 if the CP is 77762.07 Tons or less to 1 if the CP is $Z_2 = 315610.80$ Tons or more and the satisfaction level associated with EG rises from 0 for 19.43 Million Man days or less to 1 for EG $Z_3 = 24.86$ Million Man days and more.

Table 2. Solution for the NB, CP, EG and MU by LPP and MOFLP model.

S. N.	Crop and Season	Solution for Maximization of				Compromised Solution ($\lambda = 0.680$)
		NB (Z_1) (ha)	CP (Z_2) (ha)	EG (Z_3) (ha)	MU (Z_4) (ha)	Area of Crop (ha)
1	Sugarcane (P)	2750	2750	0	2750	1758.90
2	Banana (P)	1375	1375	0	1375	1375
3	Chilies (TS)	2750	2750	2750	2750	2750
4	L S Cotton (TS)	0	0	22895	22895	21026.67
5	Sorghum (K)	10996	10996	10996	10996	10996
6	Paddy (K)	9158	9158	9158	9157.20	9158
7	Sorghum (R)	12013.49	13737	13737	13737	0
8	Wheat (R)	22895	22895	22895	9481.37	22895
9	Gram (R)	4579	2774.70	4579	0	4579
10	Groundnut (HW)	0	0	1368.03	2750	0
	Net Cropped Area (Ha)	66516.49	66435.70	88378.03	75891.57	74538.57

NB: $Z_1 = 1180.33$ (Z_1^+) (Million Rs); $Z_2 = 315448.20$ (Tons); $Z_3 = 19.54$ (Million Man Days); $Z_4 = 59642.34$ (Tons);
Irrigation Intensity (%) = 70.85
CP: $Z_1 = 1175.63$ (Million Rs); $Z_2 = 315610.80$ (Z_2^+) (Tons); $Z_3 = 19.43$ (Z_3^-) (Million Man Days); $Z_4 = 59815.31$ (Z_4^-) (Tons);
Irrigation Intensity (%) =70.76
EG: $Z_1 = 892.76$ (Z_1^-) (Million Rs); $Z_2 = 77762.07$ (Z_2^-) (Tons); $Z_3 = 24.86$ (Z_3^+) (Million Man Days); $Z_4 = 108995.10$ (Tons);
Irrigation Intensity (%) = 94.13
MU: $Z_1 = 1059.16$ (Million Rs); $Z_2 = 300763.20$ (Tons); $Z_3 = 20.82$ (Million Man Days); $Z_4 = 122088.80$ (Z_4^+) (Tons);
Irrigation Intensity (%) = 80.83
Compromised Solution: $Z_1 = 1088.46$ (Million Rs); $Z_2 = 241003$ (Tons); $Z_3 = 23.13$ (Million Man Days); $Z_4 = 111454.70$ (Tons);
Irrigation Intensity (%) = 79.40

(+ve is the best value/aspired level of objective and −ve is the worst value/lowest acceptable level of objective).

Similarly, the level of satisfaction associated with MU rises from 0 if the MU is 59815.31 Tons or less to 1 if the MU is $Z_4 = 122088.80$ Tons or more. The maximum satisfaction level of the membership functions of four participating/conflicting objectives has been designated as the 'best' achieved/compromised solution. Finally the modified form of the optimization problem (MOFLP) by introducing the dummy variable $\lambda = \min[\mu_1(X), \mu_2(X), \mu_3(X), \mu_4(X)]$ such that the objective is to:

$$\text{Maximize } \lambda$$
$$\text{Subject to,}$$

$$\left(Z_1 - 892.76 \times 10^6\right) \Big/ \left(1180.33 \times 10^6 - 892.76 \times 10^6\right) \geq \lambda$$

$$\left(Z_2 - 77762.07\right) \Big/ \left(315610.80 - 77762.07\right) \geq \lambda$$

$$\left(Z_3 - 19.43 \times 10^6\right) \Big/ \left(24.86 \times 10^6 - 19.43 \times 10^6\right) \geq \lambda$$

$$\left(Z_4 - 59815.31\right) \Big/ \left(122088.80 - 59815.31\right) \geq \lambda$$

and all other original constraint given in the model; $\lambda \geq 0$. The solution of MOFLP model is presented in **Table 2**. From this solution, it is observed that the area to be irrigated is constant in case of Chilies (TS), Sorghum (K) and Paddy (K) under LP model and MOFLP model solution. When the NB is to be maximized, then the area under irrigation is zero for LS Cotton (TS) and Groundnut (HW) because the benefit coefficient is low for these crops. Similarly, when the Crop Production is to be maximized, then the area under irrigation is zero for LS Cotton (TS) and Groundnut (HW).

Also, when the EG is to be maximized, then the area under irrigation is zero for Sugarcane (P), Banana (P). This is due to the labour requirement per ha is low and also due to the limited area under the existing cropping pattern. On the other hand, when MU is to be maximized, then the area under irrigation is zero for Gram (R) as manure requirement per ha is low and also due to the limited area under the existing cropping pattern. The area under irrigation is zero for Sorghum (R) and Groundnut (HW) if four conflicting objectives are considered simultaneously under MOFLP environment. In case of individual optimization for four objectives separately the irrigation intensity is 70.85%, 70.76%, 94.13% and 80.83% respectively, while in case of MOFLP it is 79.40%.

In case of MOFLP the irrigation intensity is more by 8.55%, 8.64%, 1.21% if we compare with individual optimization for net benefits and crop production respectively, and less by 14.73% and 1.43% if we compare with individual optimization for employment generation and manure utilization respectively.

The level of satisfaction for a compromised solution for four conflicting objectives under fuzzy environment is works out to be $\lambda = 0.68$. The MOFLP compromised solution provides NB = 1088.46 (Million Rupees), CP = 241003 (Tons), EG = 23.13 (Million Man days) and MU = 111454.70 (Tons) respectively.

The results of this individual maximization of the two different objectives are used to construct the linear membership function for each objective taking the help of the best (+) and worst (−) value of the same. The membership functions are shown graphically in **Figure 6** and **Figure 7**. The same membership functions are written in the form of mathematical Equations (11-12). The results are shown in **Table 3**.
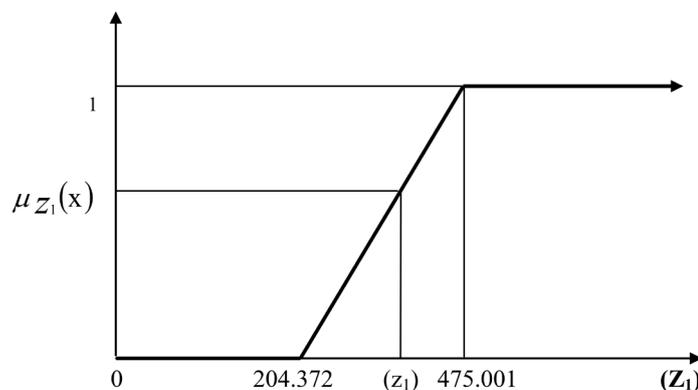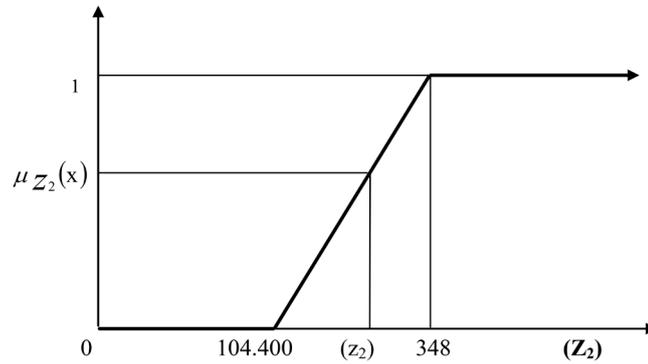

Figure 6. Membership function for Z_1 (Mm^3).

Figure 7. Membership function for Z_2 (Mm^3).

Table 3. Solution for maximization of RI and RP by LPP and MOFLP model.

S. N.	Month	Solution for Maximization of Releases (Mm^3)				Compromised Solution ($\lambda = 0.533$)	
		RI	RP	RI	RP	RI (Mm^3)	RP (Mm^3)
1	June	2.929	8.700	2.136	29.000	2.136	9.493
2	July	20.830	8.700	6.249	29.000	6.249	27.960
3	August	37.640	8.700	11.292	29.000	37.640	29.000
4	September	46.020	8.700	13.806	29.000	46.020	29.000
5	October	132.010	8.700	39.603	29.000	125.339	29.000
6	November	127.050	8.700	38.115	29.000	38.115	29.000
7	December	42.180	8.700	26.829	29.000	26.829	29.000
8	January	30.204	8.700	30.204	29.000	30.024	17.032
9	February	9.006	8.700	9.006	29.000	9.006	8.700
10	March	8.694	8.700	8.694	29.000	8.694	8.700
11	April	10.674	8.700	10.674	29.000	10.674	8.700
12	May	7.764	8.700	7.764	29.000	7.764	8.700
	Total	475.001 (Z_{1Max})	104.400 (Z_{2Min})	204.372 (Z_{1Min})	348.000 (Z_{2Max})	348.670	234.285

$$\mu_{z_1}(x) = \begin{cases} 1 & z_1 \geq 475.001 \\ \dfrac{(z_1 - 204.372)}{(475.001 - 204.372)} & 204.372 < z_1 < 475.001 \\ 0 & z_1 \leq 204.372 \end{cases} \tag{11}$$

$$\mu_{z_2}(x) = \begin{cases} 1 & z_2 \geq 348 \\ \dfrac{(z_2 - 104.400)}{(348 - 104.400)} & 104.400 < z_2 < 348 \\ 0 & z_2 \leq 104.400 \end{cases} \tag{12}$$

The membership functions $\mu_1(X)$, and $\mu_2(X)$ of the fuzzy sets characterizing the objective functions rise linearly from 0 to 1 at the highest achievable value of $Z_1 = 475.001$ Mm^3 and $Z_2 = 348.00$ Mm^3 respectively. The level of satisfaction associated with RI rises from 0 if the RI is 204.372 Mm^3 or less to 1 if the total RI is $Z_1 = 475.001$ Mm^3 or more. The level of satisfaction with respect to RP rises from 0 if the RP is 104.400 Mm^3 or less

to 1 if the RP is $Z_2 = 348$ Mm^3 or more. The maximum level of satisfaction from the membership functions of two participating/conflicting objectives has been designated as the 'best' achieved/compromised solution.

The other main objective functions of the present study considering the Equations (5), (6) of the LPP model, which are the maximization of the releases for irrigation and releases for hydropower of the Jayakwadi Project Stage-II. These objective functions are maximized separately subjected to constraints using the LINGO 13 (Language for INteractive General Optimization) optimization software. Finally the modified form of the optimization problem (MOFLP) by introducing the dummy variable $\lambda = \min[\mu_1(X), \mu_2(X),]$ such that the objective is to:

$$\text{Maximize } \lambda$$
$$\text{Subject to}$$

$$\left(Z_1 - 204.372 \times 10^6\right) \Big/ \left(475.001 \times 10^6 - 204.372 \times 10^6\right) \geq \lambda$$

$$\left(Z_2 - 104.400 \times 10^6\right) \Big/ \left(348 \times 10^6 - 104.400 \times 10^6\right) \geq \lambda$$

and all other original constraint in the model; $\lambda \geq 0$. The solution of MOFLP is presented in **Table 3**. The compromised solution yields the level of satisfaction (λ) = 0.533 for maximizing the releases for irrigation and power simultaneously by satisfying the constraint of the system under consideration. The compromised solution provides the optimal releases, *i.e.* RI = 348.670 Mm^3 and RP = 234.285 Mm^3 respectively.

4. Conclusions

The objective of the study is to develop the MOFLP models for optimal cropping pattern that maximizes Net Benefits, Crop Production, Employment Generation and Manure Utilization simultaneously and also for maximization of releases for irrigation and power for optimal operation of the reservoir. To achieve this, max-min approach based MOFLP models have been developed and applied to Jayakwadi Project Stage II, Maharashtra State, India.

The observations from the present study are as given below:

- This study proposes a basis for irrigation planning as an integrated approach.
- The level of satisfaction for a compromised solution for four conflicting objectives under fuzzy environment is works out to be $\lambda = 0.680$. The MOFLP compromised solution provides NB = 1088.46 Million Rupees, CP = 241003 Tons, EG = 23.13 Million Man days and MU = 111454.70 Tons respectively and irrigation intensity is 79.40%.
- The results of the application of MOFLP model for reservoir operation indicate that the maximum level of satisfaction (λ) is 0.533 achieved by maximizing both the objectives simultaneously and the corresponding values of RI and RP are 348.670 Mm^3 and 234.285 Mm^3 respectively.
- The present model will be helpful for the decision maker to take decisions under conflicting situations when planning for different objectives simultaneously.
- The developed models are capable to trace out an integrated irrigation planning with prime consideration for economic, social and environmental issues.
- The results obtained under the present study are sensitive to the changes in the market price of the crop, cost of crop production, unit labour cost, and unit manure cost and water availability.

Acknowledgements

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