# Fuzzy Nonlinear Programming In Multiobjective Environment For Irrigation Planning

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Fuzzy Nonlinear Programming, Nonlinear Membership Function, Irrigation Planning, Multiobjective Optimization.

**ABSTRACT**
Multiobjective irrigation planning in fuzzy framework is gaining momentum due its ability to accommodate uncertainty in the chosen objectives in the form of membership functions. Uncertainty in market prices of inputs and end products, spatial and temporal variation of yield and availability of labour makes the irrigation planning more complex and volatile in the developing country scenario. In this regard, three conflicting objectives, namely, net benefits (BM), agricultural production (PM) and labour employment (LM) are considered in Multiobjective Optimization framework. Application potentiality of present methodology is explored with a case study of Khadakwasla complex irrigation project, Maharashtra, India. The complex includes three dams as storage reservoirs, Janai-Sirsai Lift Irrigation Scheme (JSLIS), Purandar Lift Irrigation Scheme (PLIS), which provides irrigation to 101326 ha in Pune district. The effect of reuse of wastewater on the planning scenario is also studied. Objective functions are assumed as fuzzy and inflows as stochastic. Nonlinear membership functions are assumed for three objectives. Nonlinearity expressed in terms of exponent β, may vary/ be constant for each membership function depending on the perception of decision maker. Three objectives are solved as independent problems to know the tolerance levels for each objective and used as the basis for formulating membership functions. Outcome of the model formulated in Multiobjective perspective includes degree of satisfaction that represents the efficiency of the solution methodology, cropping pattern, storage, release, ground water and waste water policies. It is observed that the optimum values for linear membership functions of labour employment($\beta_1$=1), production($\beta_2$=1) and net benefits($\beta_3$=1) scenario are,7952016 Man-days, 2365184 Tons and 2296.75 Million Rupees respectively with degree of satisfaction 0.61 and irrigation intensity of 74.71%. Extensive analysis was performed with various values of β to ascertain their impact on the outcome. In almost all scenarios significant increase in irrigated area is observed as compared to existing. From outcome, it is observed that irrigation intensity is gradually decreasing in nonlinear fashion. Degree of satisfaction λ decreases from 0.61 to zero at β=7. Overall project intensity of irrigation decreases from 74.71 % to 68.88%. In scenario 2, the overall intensity of irrigation is varying from 69.87 % to 74.69 %. Degree of satisfaction is decreasing from 0.78 to 0.40 with increase in $\beta_1$ values from 0.1 to 7 ($\beta_2$= $\beta_3$=1). In scenario 3, intensity of irrigation was observed to be varying from 73.33 % to 74.79 %. Degree of satisfaction is decreasing from 0.80 to 0.42 with increase in $\beta_2$ value from 0.1 to 7 ($\beta_1$=$\beta_3$=1). In scenario 4, the overall intensity of irrigation is varying from 72.98 % to 74.74 %. Degree of satisfaction is decreasing from 0.75 to 0.53 with increase in $\beta_3$ value from 0.1 to 7 ($\beta_1$= $\beta_2$=1). It is inferred from above analysis that effect of β values on degree of satisfaction is significant (along with other outcomes) indicating that careful selection of parameters for membership function is essential for possible implementation of the methodology to real world planning problems.

## 1. INTRODUCTION

Sources of fresh water are getting exhausted and development of new water resources is cost intensive and sometimes may not be practical. In developing countries and especially in the water scarcity areas greater compatibility between water used for domestic purposes, waste water generated and agriculture use of water is necessary for the sustainability of fresh water resources. It became imperative from sustainability perspective to use treated sewage for secondary purposes like gardening, agriculture, industrial and recreation. In this regard numerous researchers worked on various aspects relevant to irrigation planning which are as follows:

Abdulkadri and Ajibefun (1998) applied LP model for generating farm plans for National Directorate of Employment farmers, in eleven local government areas of Nigeria. They assessed the resource-use efficiency of the sampled farmers, and provided alternative farm plans that are nearly optimal. Sole cropping was suggested as the optimal cropping system for the eleven areas.

Carvallo et al. (1998) developed a nonlinear optimization model for the determination of optimal cropping patterns in the irrigated agriculture. The objective function of the model is based on crop-water-production functions, irrigation technology used, costs and prices. Results of the model show that changes in the prices of exportable products and water cost have a large impact on the cropping patterns and profit. Cai et al.(2001) discussed piece-by-piece approach to solve large nonlinear water resources management models. Prasad et al.(2006) studied optimal irrigation planning under water scarcity for the case study of Nagarjuna Sagar right canal command in south India. The results revealed that the optimization approach can significantly improve the annual net benefit with a deficit irrigation strategy under water scarcity. It is concluded from all the above studies that optimization methods are helpful for deriving the reservoir operating policies.

Raju and Nagesh Kumar (2000) analyzed the irrigation planning problem in multi objective framework with net benefits, agricultural production and labour employment as objectives for the case study of Sri Ram Sagar Project, Andhra Pradesh. They considered objectives as fuzzy and inflows as stochastic. Jairaj and Vedula (2003) studied fuzzy logic for modeling reservoir irrigation for the case study of Malaprabha Reservoir in the Krishna Basin, Karnataka State, India with the objective to maximize the annual crop water utilization. They considered inflows to the reservoir and rainfall in the reservoir command area as stochastic, whereas potential evapotranspiration is modeled as fuzzy.

Choudhari and Raj (2009) applied fuzzy linear programming method to achieve the better policy for the system operation. A sub basin of Godavari river in Maharashtra, India is taken as a case study and the fuzzification of all parameters is explored on the system. The consequences on the objectives i.e. maximization of returns from irrigation release and power releases are also studied.

In this study, three conflicting objectives, namely, net benefits (BM), agricultural production (PM) and labour employment (LM) are considered in Multiobjective Fuzzy Optimization methodology. Application potentiality of present methodology is explored with a case study of Khadakwasla complex irrigation project, Maharashtra, India.

## 2. CASE STUDY

Khadakwasla project is meant for providing irrigation facility to the scarcity areas of Pune district as well as drinking water supply to Pune Municipal Corporation (PMC), Pune Cantonment, Daund Nagar Palika and surrounding villages. The water stored is also utilized for industries in and around Pune. There are two hydropower stations of 8 MW each at the foot of Panshet dam and Warasgaon dam. The water released through these dams generates the hydropower before being discharged into Khadakwasla dam. The Khadakwasla complex project has three storage reservoirs, Panshet, Warasgaon, and Temghar with the gross storage of 871Mm$^3$, New Mutha Right Bank Canal (NMRBC) of 202 km, Janai-Sirsai Lift Irrigation Scheme (JSLIS), Purandar Lift Irrigation Scheme (PLIS),etc. Khadakwasla project provides irrigation to 101326 ha in Haveli, Daund, Baramati and Indapur talukas of Pune district. (refer Fig. 1.)

The design discharge at the head of the NMRBC is 58 m$^3$/s. The project has irrigation intensity of 61%. The overall efficiency of Khadakwasla project is 55% while that of Janai Sirsai and Purandar LIS is 63% (Water Resources Department.(2008)). Khadakwasla project serves the irrigation purpose of six talukas in Pune district. There are about 91 villages in command area, of which 18 in Haveli, 29 in Daund, 3 in Baramati and 41 in Indapur talukas of Pune district.

### 2.1. Janai-Sirsai Lift Irrigation Scheme (JSLIS)

The scheme utilizes 102 Mm$^3$ of Khadakwasla water. This water is made available by thinning / modifying the cropping pattern of original Khadakwasla project and water unutilized due to urbanization of Khadakwasla command in Haveli taluka. JSLIS irrigates 14080 ha area. The scheme consists of two lift irrigation schemes namely, Janai LIS and Sirsai LIS. The water is fed from NMRBC to existing Warvand tank for Janai LIS and Shirsuphal tank for the Sirsai LIS.

### 2.2. Purandar Lift Irrigation Scheme (PLIS)

The Purandar LIS scheme will benefit Haveli, Daund, Purandar and Baramati talukas of Pune district. The command area is hilly and situated at 250 to 350 m high above river water level. Maharashtra Krishna Valley Development Corporation (MKVDC) approved the Lift Irrigation Scheme on local villagers demand. Purandar LIS irrigates 25100 ha area.

### 2.3. Reuse of Waste Water

Pune is second largest city of Maharashtra state. A large population is dependent on Mula-Mutha river water flow, down to Pune city. These rivers finally meet Bhima river and discharge into Ujjani dam. At present the annual water requirement of Pune city for domestic purposes is around 275.16 $Mm^3$ and for PCMC it is 185 $Mm^3$. In addition to population of Pune Muncipal Corporation and Pimpri Chinchwad Muncipal Corporation (PMC and PCMC) it includes the population under three cantonments; namely, Khadki Cantonment Board (KCB), Pune Cantonment Board (PCB) and Dehu Road Cantonment Board (DRCB).

The source of water to twin city is Pavana dam which has a capacity of 297 $Mm^3$ and is about 36 km North-West of the city. The Pune city generates around 451 Million Liter per Day (MLD) of sewage. Pimpri-Chinchwad city generates 287 MLD of sewage (Tirthakar, 2009). At present, 68% of the total sewage generated by PMC and 63% sewage generated by PCMC is treated before being discharged into the rivers. Pune and PCMC under the master plan will treat 100 % of its sewage generated by the end of 2015. The right bank canal of Khadakwasla dam passes through Pune city. All the old and newly constructed sewage treatment plants of PMC and PCMC are located on or near the banks of Mula-Mutha, Pavana rivers flowing through Pune and Pimpri-Chinchwad city.

## 3. MATHEMATICAL MODELING

Three objectives are considered in the present study. The first objective of the model is to maximize the Net Benefits (BM) from the Khadakwasla, JSLIS and PLIS, after meeting the cost of ground water. The net benefit includes irrigation benefit, revenue generated from domestic water supply to PMC and water supplied to industries.

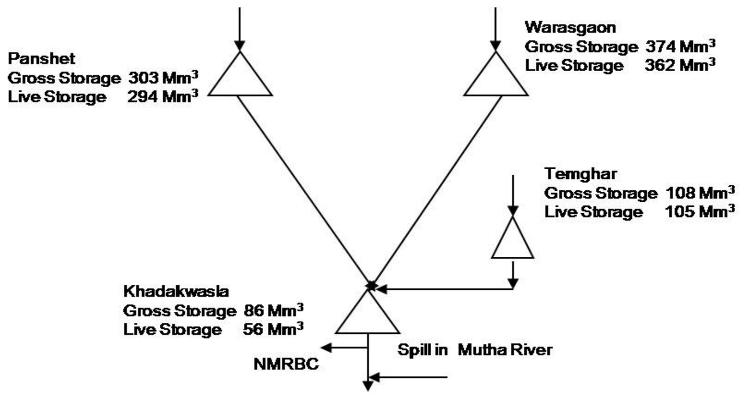


**Figure 1.** Schematic diagram of Khadakwasla Project

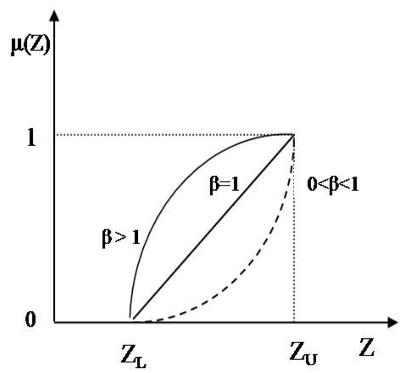


**Figure 2.** Fuzzy Membership Function

Net Benefit is expressed (in Rs.) as,

$$BM = \sum_{i=1}^{36} B_i A_i - P_{GW} \sum_{t=1}^{12} GW_t + P_{DW} \sum_{t=1}^{12} DW_t + P_{IND} \sum_{t=1}^{12} IND_t \qquad (1)$$

The second objective is to maximize production (PD) of crops under Khadakwasla, JSLIS, PLIS and expressed (in tons) as,

$$PM = \sum_{i=1}^{36} PM_i A_i \quad (2)$$

The third objective is to maximize labour employment so that the employment generated can minimize the migration. Labour employment (in man-days) is expressed as,

$$LM = \sum_{i=1}^{36} LM_i A_i \quad (3)$$

The nomenclature used is: index of the crop, name of the crop, crop season.

*Khadakwasla Project:* 1, Hybrid Bajra, K; 2, Groundnut, K; 3, Green Manure, K; 4, Hybrid Jowar, R; 5,Wheat, R; 6, LS Cotton, TS; 7, Chilies, TS; 8, Paddy-Drilled, TS; 9, Paddy-TP, TS; 10, Groundnut, HW; 11, Sugarcane, P;

*Janai-Sirsai Lift Irrigation Scheme(JSLIS):* 12, Hybrid Bajra, K; 13, Groundnut, K; 14, Green Fodder, K; 15,Vegetables, K; 16, Hybrid Jowar, R; 17,Wheat, R; 18, LS Cotton, TS; 19, Chilies, TS; 20, Paddy Drilled, TS; 21, Paddy-TP, TS; 22, Groundnut, HW; 23, Sugarcane, P.

*Purandar Lift Irrigation Scheme* (PLIS): 24, Hybrid Bajra, K; 25, Groundnut, K; 26, Green Fodder, K; 27, Vegetables, K; 28, Onion, K; 29,Tur(Pigeon pea),K; 30, Pulses, K; 31, Fodder, K; 32, Hybrid Jowar, R; 33, Gram, R; 34, Vegetables, HW; 35, Fruits, P; 36, Sugarcane, P;

K, R, TS, HW, P denotes Kharif, Rabi, Two Seasonal, Hot Weather, Perennial seasons whereas TP represents Transplanted respectively; t = Index of the month in water year, t = 1,..,12; (1=June,..,12=May); $P_{GW}$ = Cost of ground water pumping ( Rs./Mm$^3$); $P_{DW}, P_{IND}$ = Revenue from drinking water (domestic water supply) and industrial water supply respectively (Rs./Mm$^3$); $A_i$ = Area of the crop i; $B_i$ = Return from crop i (Rs./ha ); $DW_t, IND_t$ = Domestic and industrial water supply in Mm$^3$ for the month t; $PM_i$ = Production of crop i (ton/ha); $LM_i$ = Labour employment of crop i ( man-days/ha).

### 3.1. Constraints

The model formed is subjected to following constraints

*3.1.1. Continuity Equation*

The Khadakwasla reservoir is operated on monthly basis, with the inflows from upper reservoirs. (Fig. 1.) The water is supplied for the irrigation of Khadakwasla and JSLIS command through a canal system and for the drinking and industry through close conduit system, which forms part of an outflow along with evaporation and spillage. The monthly continuity equation at Khadakwasla reservoir is expressed as

$$S_{t+1} = S_t + I_t - DW_t - IR_t - EV_t - SPILL_t - IND_t - JS_t; \qquad t = 1,2,..,12. \quad (4)$$

Where $S_t$ = Reservoir storage at the end of month t; $I_t$ = Dependable inflow during month t; $IR_t$ = Irrigation water requirement of Khadakwasla during month t; $EV_t$ = Evaporation losses from reservoir in month t; $SPILL_t$ = Spillage from Khadakwasla dam during month t; $JS_t$ = Irrigation water requirement of JSLIS for the month t. All the components in continuity equation are in Mm$^3$.

*3.1.2. Land Requirement of Crops*

The total area under various crops in respective seasons should be less than or equal to Cultivable Command Area (CCA).

*3.1.3. Water Requirements of Crops*

Monthly crop water requirements ( $CWR_{it}$ ) are calculated based on the water required per ha of crop activity. It is the product of area under i$^{th}$ crop and crop water requirement in t$^{th}$ month. In absence of any crop activity, crop water requirement is assumed as zero. The releases from reservoir and waste water ( $WW$ ) added into the system through canal or lift scheme should satisfy the irrigation demand of the crops.

*3.1.3.1. Khadakwasla Project*

$$\sum_{i=1}^{11} A_i * CWR_{it} - IR_t - GW_t - 0.5WW_t = 0; \qquad t = 1,2,..,12. \tag{5}$$

Where $WW$ = Waste water utilized by Khadakwasla and JSLIS combine during month t; $CWR_{it}$ = Water requirement of crop i during t[th] month.

*3.1.3.2. JSLIS*

Eighty five percent of the water supplied to the city for domestic and industrial purposes i.e., 20.49 $Mm^3$/month is expected as waste water (Manual on Sewerage and Sewage Treatment 1993).The total waste water generated is calculated considering waste water of Pimpri-Chinchwad and Pune after giving due allowance for infiltration, industrial use, etc along the course of the river Mula and Mutha.

Pune city is growing by leaps and bounds in all directions. This urbanization has resulted in reduction of irrigation requirements/demands in distributories number 1 to14 (as these become part of Pune city). Water thus available is expected to satisfy the demand of irrigation water in the geographically elevated regions of Daund, Purandar and Baramati in Pune district, by JSLIS and Khadakwasla projects. The model deals with this situation by introducing 50 % of treated waste water for JSLIS and Khadakwasla in equations (5) and (6).

$$\sum_{i=12}^{23} A_i * CWR_{it} - JS_t - 0.5WW_t = 0; \qquad t = 1,2,..,12. \tag{6}$$

*3.1.3.3. PLIS*

JSLIS and Khadakwasla project would utilize the waste water to supplement their needs by pumping into the canal system to the tune of $WW_t$ only. The balance treated waste water is expected to flow along the Mutha River, which will be lifted by the pumps from pumping station at Koregaon Mul to satisfy the water requirements of PLIS. The mathematical model replicates the field situation by introducing the balance waste water $20.49 - WW_t$ as in equation (7).

$$\sum_{i=24}^{36} A_i * CWR_{it} - SPILL_t - (20.49 - WW_t) = 0; \qquad t = 1,2,..,12. \tag{7}$$

*3.1.4.Canal Capacity*

Total releases from the reservoirs cannot exceed the NMRBC capacity $CC_t$ . Here $CC_t$ is converted into volumetric units i.e., $Mm^3$.

$$IR_t + IND_t + WW_t + JS_t \le CC_t; \qquad t = 1,2,..,12. \tag{8}$$

Other constraints that are used in the present study are minimum and maximum reservoir storages, ground water withdrawals.

### 3.2. Fuzzy Multiobjective Optimization Modeling Approaches

Fuzzy modeling situation assume that objectives and constraints in an imprecise and uncertain situation can be represented by fuzzy sets (Zimmermann 1996; Jairaj and Vedula 2000; Ross 2010; Raju and Nagesh Kumar 2010). In fuzzy programming, the fuzziness of available resources is represented by the membership functions. In fuzzy modeling situations, objectives and/or constraints in uncertain scenario can be represented by fuzzy sets.

*3.2.1. Nonlinear Membership Function* (refer Fig. 2.)

Nonlinear membership function for any objective function/constraint Z can be expressed as:

$$\mu_Z(X) = \begin{cases} 0 & \text{for} \quad Z \le Z_L \\ \left[ \dfrac{Z - Z_L}{Z_U - Z_L} \right]^{\beta} & \text{for } Z_L < Z < Z_U \\ 1 & \text{for} \quad Z \ge Z_U \end{cases} \tag{9}$$

Where $Z_U$, $Z_L$ are maximum and minimum acceptable levels of the objective and β provides the basis for desired shape of membership function (β=1 for linear; β >1 and β <1 for nonlinear). Similar membership conditions holds good for constraints also (Sasikumar and Mujumdar 1998).
Introducing a new variable λ, the problem can be reorganized as:
Maximize λ
Subject to

$$\left[\mu_{G_J}(X)\right]^{\beta} \geq \lambda \qquad \text{for each objective function } j = 1,2,..,n$$

$$\left[\mu_{C_i}(X)\right]^{\beta} \geq \lambda \qquad \text{for each constraint } i = 1,2,..,m$$

$$0 \leq \lambda \leq 1$$

and all other existing constraints and bounds. Here $\mu_{G_J}$ and $\mu_{c_i}$ represents the membership functions for objective and constraints respectively.

## 4. RESULTS AND DISCUSSION

Optimization of the Multiobjective fuzzy problem is performed with linear programming algorithm. In the present study, 75% dependable inflow scenario is considered, which represent general water resources planning problem in India.(Maji and Heady 1980).In addition exploring the conjunctive use concept along with waste water reuse is also initiated.

Initially the model is solved for 75% dependable inflow with ground water, for three objectives of maximization of benefit, production and labour employment; independently The solutions so obtained with single objective optimization problem are used as basis for Multiobjective Optimization Problem (MOP) formulation i.e. finding the upper ( $Z_U$ ) and lower ( $Z_L$ ) bounds of objective function.

The solution with linear membership function for all three objectives suggests cropping pattern, monthly water storage policy, water use policy. Fig.3., Fig.4. and Fig.5 suggest the crop pattern for Khadakwasla, JSLIS and PLIS command. The same is compared with the existing crop pattern. Area under crop A1, A2, A3, A6, A7, A10 and A11 increases while A4, A5, A8 and A9 decreases. JSLIS crop pattern (Fig.4.) suggests, increase in area under all the crops, PLIS crop pattern as in Fig.5. also suggest increase in area under each crop. Irrigation intensity for khadakwasla command increases by 8.72%, JSLIS by 26.70% and PLIS by 32.19%. The optimum labour employment is 7952016 Man-days, production 2365184 Tons and net irrigation benefits 2296.75 Million Rupees, with degree of satisfaction 0.61 and overall irrigation intensity for the project is 74.71%. Fig.6. shows monthly water use policy for khadakwasla command. In an integrated environment, total demand for Khadakwasla command will be shared by fresh water 318.82 $Mm^3$, treated waste water 37.89 $Mm^3$ and ground water 100.13 $Mm^3$. Fig.7 shows monthly water use policy for JSLIS command. Total demand for JSLIS command will be shared by fresh water 64.30 $Mm^3$ and treated waste water contribution of 37.89 $Mm^3$. PLIS command shall utilize 170.09 $Mm^3$ of treated waste water annually. Fig.8. show monthly storage policy for khadakwasla dam.

**Table 1.** Sensitivity Analysis: Uniform variation of (β) with stochastic inflow

| Characteristics | β1=β2=β3= 1 | β1=β2=β3= 3 | β1=β2=β3= 5 | β1=β2= β3 = 7 |
|---|---|---|---|---|
| Area Under Crop in Khadakwasla ("100" ha) | 675.61 | 675.61 | 723.95 | 720.78 |
| Intensity of Irrigation in % | 66.44 | 66.44 | 71.19 | 70.88 |
| Area Under Crop in JSLIS ("100" ha) | 196.25 | 196.25 | 197.40 | 197.57 |
| Intensity of Irrigation in % | 99.59 | 99.59 | 100.18 | 100.26 |
| Area Under Crop in Purandar ("100" ha) | 335.10 | 335.10 | 236.10 | 194.51 |
| Intensity of Irrigation in % | 83.44 | 83.44 | 58.79 | 48.43 |
| Total Area Under Crop ("100" ha) | 1206.95 | 1206.95 | 1157.45 | 1112.86 |
| Intensity of Irrigation in % | 74.71 | 74.71 | 71.64 | 68.88 |
| Benefits in 'Million Rs' | 2296.754 | 2296.755 | 2266.371 | 2208.558 |
| Production in 'Metric Ton' | 2365184 | 2365184 | 2312342 | 2222871 |
| Labour in 'Man Days' | 7952016 | 7952016 | 7822995 | 7604542 |
| Degree of Satisfaction 'λ' | 0.61 | 0.23 | 0.01 | 0.00 |

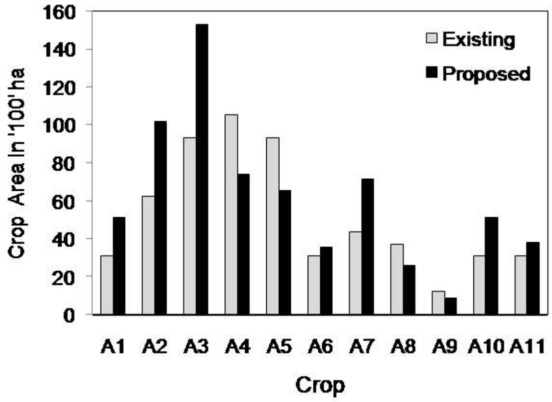


**Figure.3.** Khadakwasla Crop Pattern

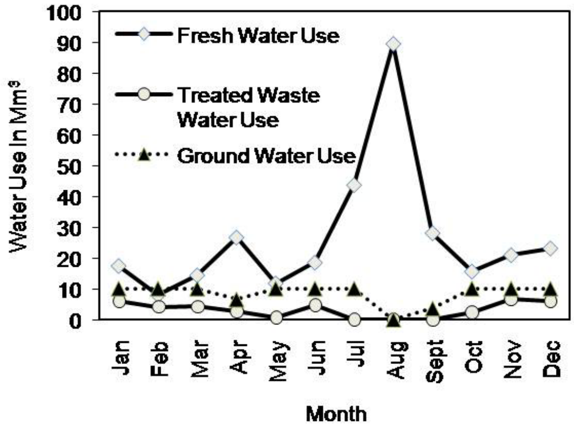


**Figure.6.** Khadakwasla Water Use Policy

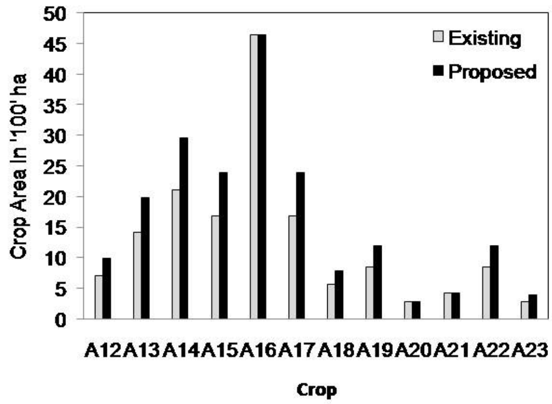


**Figure.4.** JSLIS Crop Pattern

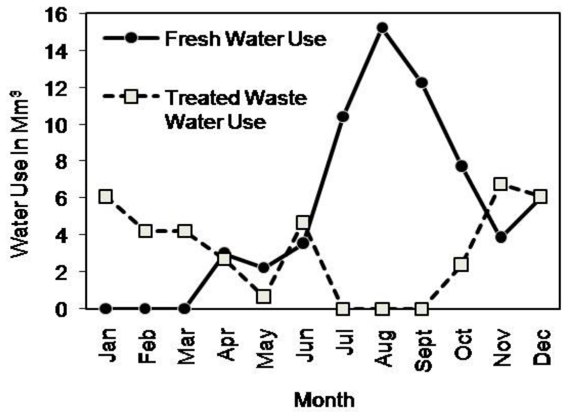


**Figure.7.** JSLIS Water Use Policy

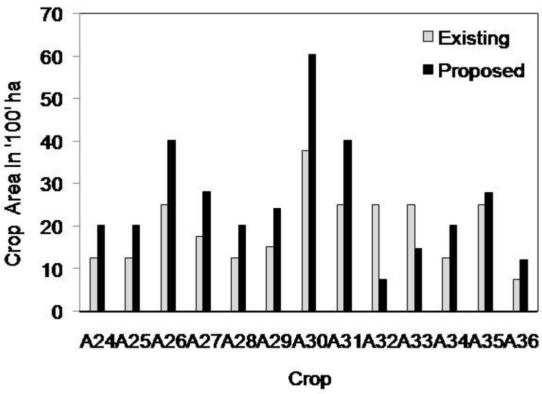


**Figure.5.** PLIS Crop Pattern

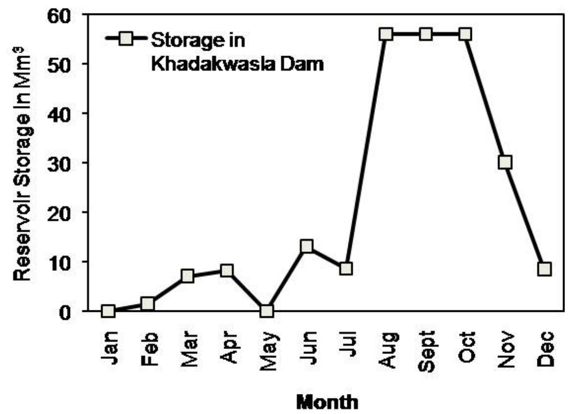


**Figure.8.** Khadakwasla Storage Policy

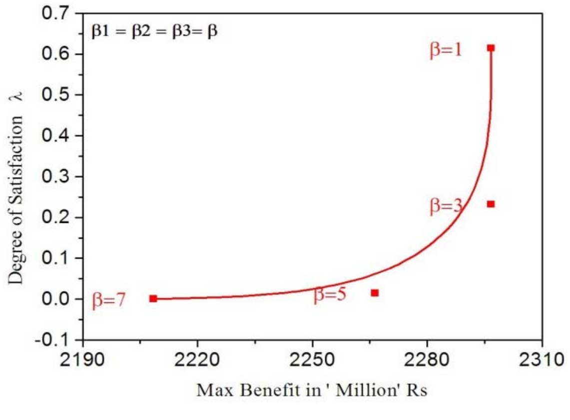


**Figure.9.** Nonlinearity effect on Net Benefits & λ

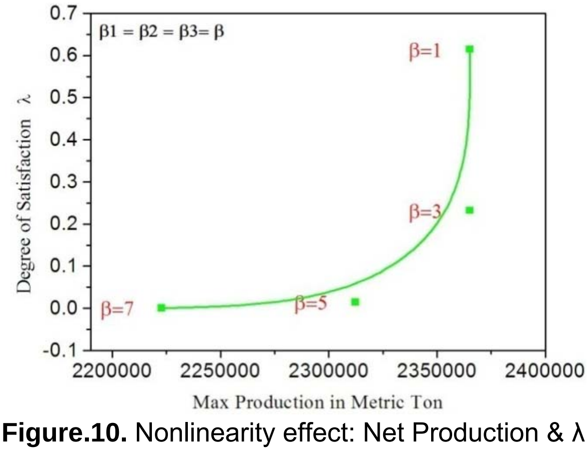


**Figure.10.** Nonlinearity effect: Net Production & λ

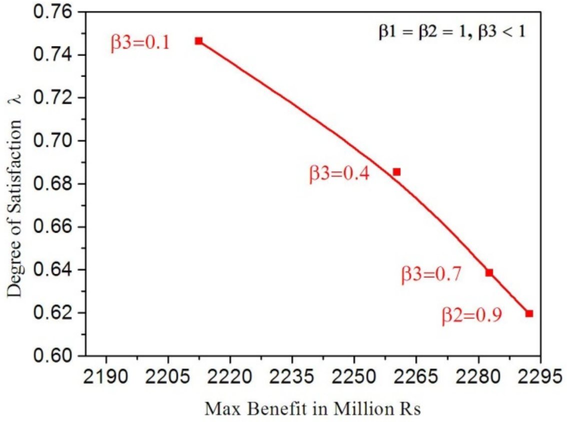


**Figure. 11.** Effect on Net Benefits & λ; with β3<1

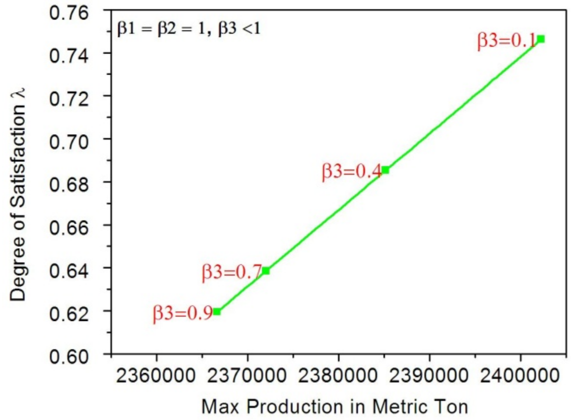


**Figure. 12.** Effect on Net Production & λ; with β3<1

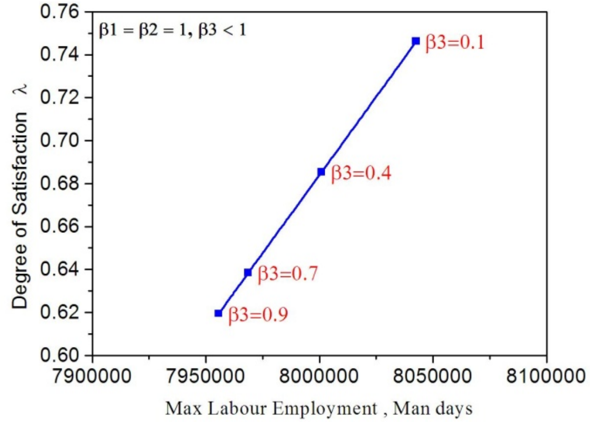


**Figure. 13.**Effect on Labour Employment & λ; with β3<1

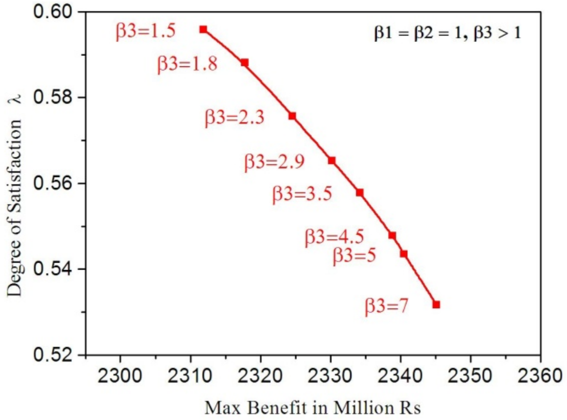


**Figure. 14.** Effect on Net Benefits & λ; with β3>1

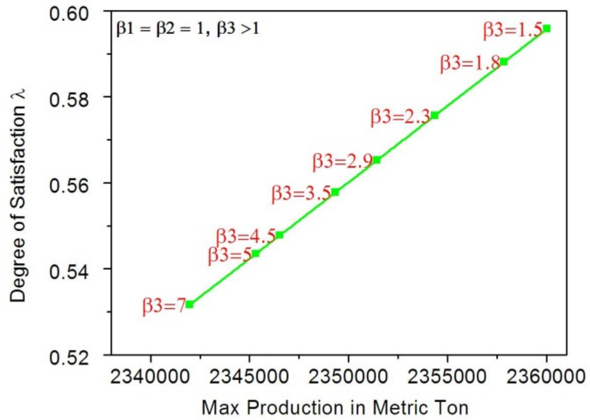


**Figure. 15.** Effect on Net Production & λ; with β3>1

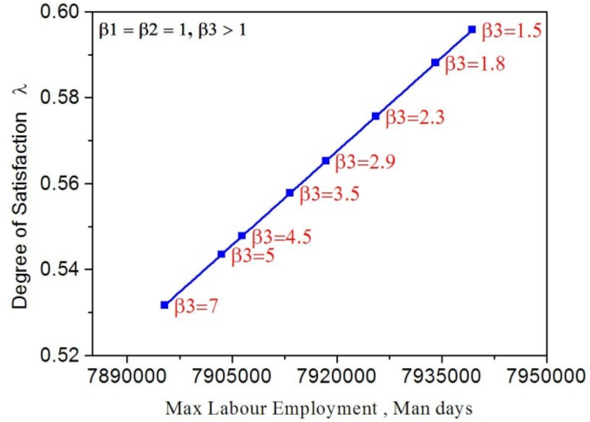


**Figure. 16.**Effect on Labour Employment & λ; with β3>1

Sensitivity analysis was carried out to observe the effect of variation of exponent of membership functions developed for each objective. The objectives are maximization of net benefits, maximization of production and maximization of labour employment (refer equation 9). β1 is the exponent of equation pertaining to objective function of maximizing Labour Employment (LM), β2 is the exponent of equation pertaining to objective function of maximizing Production (PM) and β3 is the exponent of equation pertaining to objective function of maximizing Benefits (BM).The solutions here can give standard set of curves for a particular project. **β**1, **β**2 and **β**3 values for that project for a particular year can be decided; corresponding to these values a ready / calibrated curve can be used to predict the objective values. It was observed that the model necessarily does not give solution for every nonlinearity value of objective function. The local optimal solutions were found only for selective values and their combinations. Table1. gives the results with uniform variation of β, exponent of a membership function representing particular objective. The result shows that the value of objective function reduces with increase in power of exponent and the degree of satisfaction λ also reduces to zero, indicating no association with each other. Various combinations that were tried and for which solutions were obtained are represented in Table.2. It can be concluded that the nonlinearity is followed in the results of respective parameters.

**Table 2.** Comparative Results of Sensitivity Analysis

| Scenario | Summary of Results |
|---|---|
| 1. Uniform variation of β value in membership function for all the three objectives.<br>β1= β2= β3= 1, 3, 5, 7 | Fig.9. and Fig.10. show variation of Degree of Satisfaction 'λ' with exponent of objective function. Intensity of irrigation is gradually decreasing in nonlinear fashion. Degree of satisfaction λ decreases from 0.61 abruptly to zero at β=7 for all the three objectives. Overall project intensity of irrigation decreases from 74.71 % to 68.88%. |
| 2. Non uniform variation of β value in membership functions for all the three objectives.<br>β2 = β3 =1;<br>β1 = 0.1, 0.4, 0.7, 0.9, 1.5, 1.8, 2.3, 2.9, 3.5, 4.5, 5, 7 | The overall intensity of irrigation is varying from 69.87 % to 74.69 %. Degree of satisfaction is decreasing from 0.78 to 0.40 with increase in β1 value from 0.1 to 7 (β2= β3=1) |
| 3.β1 = β3 =1;<br>β2 = 0.1, 0.4, 0.7, 0.9, 1.5, 1.8, 2.3, 2.9, 3.5, 4.5, 5, 7 | The overall intensity of irrigation was observed to be varying from 73.33 % to 74.79 %. Degree of satisfaction is decreasing from 0.80 to 0.42 with increase in β2 value from 0.1 to 7 (β1= β3=1) |
| 4.β1= β2 = 1;<br>β3 = 0.1, 0.4, 0.7, 0.9, 1.5, 1.8, 2.3, 2.9, 3.5, 4.5, 5, 7 | Fig.11. to Fig.16. show variation of Degree of Satisfaction λ with exponent of net benefit as objective function; β3<1 and β3>1. The overall intensity of irrigation was observed to be varying from 72.98 % to 74.74 %.Degree of satisfaction is decreasing from 0.75 to 0.53 with increase in β3 value from 0.1 to 7 (β1= β2=1) |

## 5. CONCLUSIONS

Khadakwasla project evaluation is done under the changing scenarios, for general irrigation planning. The effect of conjunctive use of ground water to account for scarcity of irrigation supplies and use of treated waste water for irrigation through extended command of JSLIS and PLIS is evaluated. The results indicate that there is 8.72%, 26.70% and 32.19 % increase in Khadakwasla, JSLIS and PLIS command respectively. The model developed in the present study can handle the uncertainty in the crop yield, crop prices and labour availability from socio-economic point of view. The concept of Fuzzy Nonlinear Multiobjective Programming can be effectively used for Irrigation planning by the Irrigation managers. The result underlines the need of integrated reservoir planning.

It is inferred that effect of β values on degree of satisfaction is significant (along with other outcomes) indicating that careful selection of parameters for membership function is essential for possible implementation of the methodology to real world planning problems.


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