

Integrated Sustainable Irrigation Planning with Multiobjective Fuzzy Optimization Approach

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Received: 14 December 2012 / Accepted: 16 June 2013 /
Published online: 12 July 2013
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Abstract Multiobjective fuzzy methodology is applied to a case study of Khadakwasla complex irrigation project located near Pune city of Maharashtra State, India. Three objectives, namely, maximization of net benefits, crop production and labour employment are considered. Effect of reuse of wastewater on the planning scenario is also studied. Three membership functions, namely, nonlinear, hyperbolic and exponential are analyzed for multiobjective fuzzy optimization. In the present study, objective functions are considered as fuzzy in nature whereas inflows are considered as dependable. It is concluded that exponential and hyperbolic membership functions provided similar cropping pattern for most of the situations whereas nonlinear membership functions provided different cropping pattern. However, in all the three cases, irrigation intensities are more than the existing irrigation intensity.

Keywords Multiple objectives · Fuzzy optimization · Irrigation · Cropping pattern · Waste water

1 Introduction

Fresh water resources are dwindling day by day due to enormous increase in demand from sectors like irrigation, drinking water and industry. Simultaneously quality of water is deteriorating due to the indiscriminate use of groundwater to the intolerable levels, improper management of waste water and pollution of rivers. Complexities in quality and quantity characteristics of water make water resources planning fuzzier. Timely availability of water

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along with other resources in sustainable environment is critical to ensure adequate food supplies and farm income. Keeping this in view, optimal utilization of land and water resources for efficient irrigation planning is essential due to increasing requirement of food grain production. The objectives of irrigation planning could be maximizing net benefits, crop production, labour employability, hydropower output and minimizing fertilizer requirement, cost of crop production etc. These objectives when considered simultaneously are conflicting in nature. Therefore, multiobjective irrigation planning is gaining importance to satisfy the conflicting objectives in a developing country scenario (Loucks et al. 1981). Uncertainty in inflows, along with evaporation from reservoir, water quality and water pricing are the important components that significantly affect the planning scenario. Shortage of water resources, if any, can be augmented from other sources such as groundwater and waste water utilization after suitable treatment (FAO 2012). In this regard, input–output mapping can be obtained where available inflows, existing cropping pattern and various water demands can result in compromised cropping pattern, reservoir operation policies and the values of net benefits, crop production, labour employment. This may form part of the water conservation strategies that can be adopted at the various levels.

On the other perspective, fuzzy logic is gaining strength in multiobjective optimization scenario due to its simple and flexible approach that reorganizes multiobjective planning problem into a single objective environment (Raju and Nagesh Kumar 2010). In the present study, three membership functions, namely, nonlinear, hyperbolic and exponential are analyzed in multiobjective optimization scenario, considering maximizing net benefits, crop production and labour employment as objectives. Subsequent sections present literature review, case study, mathematical modeling, description about membership functions, results and discussion, summary and conclusions, followed by references.

2 Literature Review

Optimization methods are effectively utilized for deriving the reservoir operating policies. Relevant literature review is presented in Table 1 to analyze the various aspects of multireservoir, multiobjective irrigation planning and management aspects.

Majority of studies discussed in Table 1 considered multiobjective optimization problem application to various case studies. They considered linear membership function approach and solved the same using linear programming. However, no study considers simultaneously nonlinear, hyperbolic and exponential membership function methodology that can be assigned to various chosen objectives in the multireservoir multiobjective scenario.

Keeping above limitations in view, the present paper pursues nonlinear, hyperbolic and exponential membership functions that can be assigned to each of the objectives, namely, net benefits, crop production and labour employment. Uncertainty in inflows is handled using dependable level approach (Loucks et al. 1981). Proposed methodology is applied to the case study of Khadakwasla complex irrigation project, India.

3 Case Study

Khadakwasla complex irrigation project consists of four major dams, namely, Khadakwasla, Panshet, Warasgaon, and Temghar, located near Pune city of Maharashtra State, India. Figure 1. presents schematic diagram of Khadakwasla complex irrigation project. The Khadakwasla complex envisaged construction of three dams namely Panshet, Warasgaon

Table 1 Literature review

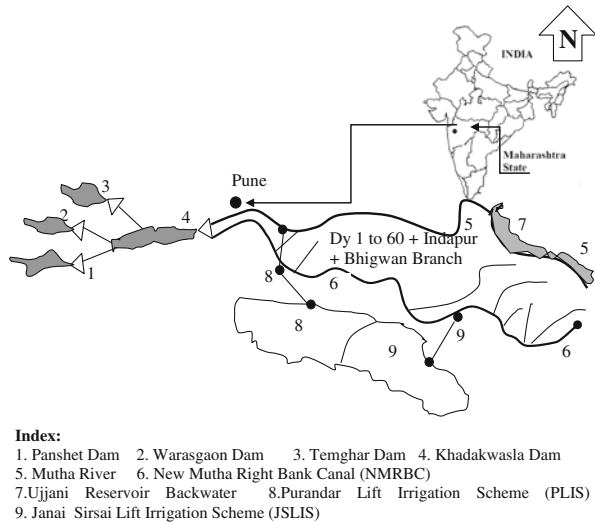
Author	Research work reported
Yeh 1985; Wurbs 1993; Labadie 2004;	Gives excellent review of research conducted in recent past in water resources system optimization and simulation studies.
Carvalho et al. 1998	A nonlinear optimization model for the determination of optimal cropping pattern in the irrigated agriculture was developed. The objective function of the model is mainly based on crop-water production functions, product costs and outcome from the planning model are optimal cropping pattern, irrigation water, labor requirements and profit. Sensitivity analysis is also performed on various parameters. It is concluded that water cost have a large impact on the cropping pattern and profit.
Raju and Nagesh Kumar 2000	Three objectives, namely, net benefits, agricultural production and labour employment are considered in fuzzy multiobjective optimization scenario and methodology is applied to a case study of Sri Ram Sagar Project. Linear membership functions were considered for three objective functions. They used linear programming as the solution approach. It is observed from multiobjective optimization solution that net benefits, agricultural production and labour employment have decreased by 2.38 %, 10.26 % and 7.22 % as compared to ideal values.
Jairaj and Vedula 2000	Formulated fuzzy mathematical programming model to a three reservoir system in the Upper Cauvery River basin, South India with the objective to minimize the sum of deviations of the irrigation withdrawals from their target demands, on a monthly basis, over a year. Uncertainty in reservoir inflows is considered by treating them as fuzzy sets and irrigation demands are considered as deterministic. It is concluded that the proposed approach gives steady state solution with less effort as compared to stochastic dynamic programming.
Jairaj and Vedula 2003	Proposed mathematical programming model to determine the annual relative yield of crops, its reliability to a case study of Malaprabha reservoir in the Krishna Basin, India. Inflow to the reservoir and rainfall are considered as random variables, whereas potential evapotranspiration is considered as a fuzzy set. They assumed linear membership function.
Vedula et al. 2005	Developed a mathematical model to achieve maximum sum of relative yields of crops over a year subject to mass balance at the reservoir, soil moisture balance for individual crops, and governing equations for groundwater flow. Outcome is optimal conjunctive use policy for irrigation of multiple crops in a reservoir-canal-aquifer system of Chitradurga, Karnataka State, India.
Consoli et al. 2008	Proposed two different objective functions, namely, minimization of reservoir release deficit from the irrigation demand and the maximization of net benefit by the demand sector to develop operating rules for the operation of Pozzillo reservoir, Eastern Sicily. They used nonlinear programming, constraint method, interactive analytical <i>Step method</i> to find the best compromise solution.
Mujumdar and Ghosh 2008	Discussed fuzzy logic-based approaches adopted in addressing uncertainty in water resource systems modeling, applications of fuzzy rule-based systems and fuzzy optimization.
Regulwar and Anand Raj 2009	Proposed multi objective (maximization of irrigation releases and maximization of hydropower production) multireservoir operation model that can solved using Genetic algorithm in fuzzy environment. Linear membership function is assumed for fuzzifying two chosen objectives. Determined operation policy is compared with the actual average operation policy for Jayakwadi Stage-I reservoir.

Table 1 (continued)

Author	Research work reported
Lu et al. 2009	Two Step Infinite α -cuts Fuzzy linear Programming method is developed to generate more reliable optimal results than conventional fuzzy linear programming. Methodology is applied to a hypothetical agricultural irrigation system in North America.
Kagade and Bajaj 2009	Used Fuzzy approach with different linear and nonlinear membership functions to solve the multi-objective assignment problem of minimization type.
Deep et al. 2009	Adopted fuzzy interactive method for efficient management of multipurpose multireservoir problems. Fuzzy membership functions of various objectives are framed in each iteration and combined into a single objective using the product operator and solved using genetic algorithm.
Rani and Moreira 2010	Discussed simulation, optimization and combined simulation–optimization modeling approach, classical optimization techniques, evolutionary computations, fuzzy set theory and artificial neural networks, in reservoir system operation studies with reference to water resources planning context.
Han et al. 2011	Developed a multi-objective linear programming model with interval parameters and applied to allocation of multi-source water resources with different water qualities for the Dalian city. It is concluded that allocation of multi-source water resources to multiple users is improved due to incorporation of uncertain factors into the model.
Raul et al. 2012	Employed irrigation scheduling model to predict actual crop yield under different irrigation strategies for canal command of the Hirakud project of Orissa, India. It is concluded that net annual return was found to decrease with the increase in the level of deficit with maximum return under full irrigation strategy. Analyzed
Regulwar and Gurav 2012	Proposed Multi Objective Fuzzy Linear Programming model to solve the problem of optimal cropping pattern in an irrigation system and takes into consideration the fuzziness of all parameters. Four objective functions, namely, net benefits, crop production, employment generation and manure utilization were used for the study. The model was applied to a case study of Jayakwadi Project Stage I, across river Godavari located in Maharashtra, India.
Darshana et al. 2012	The crop water requirement, time and depth was estimated using CROPWAT. The evolutionary algorithm (GANetXL) was used for the optimal planning of cropping pattern, maximization of net benefits and minimization of irrigation water requirements for the study area of Holeta catchment, Ethiopia.
Tan et al. 2013	Proposed improved method of superiority–inferiority-based inexact fuzzy-stochastic quadratic programming (SI-IFSQP) which is an improvement over the conventional nonlinear programming. Multiple uncertainties, scale economies and dynamic parameters are effectively reflected in the model and generates series of long-term water supply strategies under a number of economic, environmental, ecological, and water-security targets.

and Temghar as storage reservoirs, Khadakwasla as service reservoir, Janai-Sirsai Lift Irrigation Scheme (JSLIS), Purandar Lift Irrigation Scheme (PLIS) and hydropower generation (8 MW each) at Panshet and Warasgaon. The water released through Panshet and

Fig. 1 Index map of Khadakwasla project



Warasgaon dams generates the hydropower before being discharged into Khadakwasla dam. Present study does not account for hydropower as the source point is considered as Khadakwasla dam.

New Mutha Right Bank Canal (NMRBC) takes off from Khadakwasla dam and is 202 km long. Khadakwasla complex project provides irrigation to 102 326 ha in Pune district. The design discharge at the head of the NMRBC is $58 \text{ m}^3/\text{s}$. It has four branch canals and 60 distributaries. The existing crop pattern suggests irrigation intensity of 61 % for Khadakwasla, 71 % for JSLIS and 63 % for PLIS (Water Resources Department 2008).

Sources of fresh water are getting exhausted and development of new water resources is cost intensive and time consuming. Greater compatibility between water used for domestic purposes, waste water generated that can be utilized after proper treatment and agriculture use of water is necessary for the sustainability of fresh water resources. Use of waste water also provides nutrient input to crops, thus reducing use of nitrogen (N) and phosphorous (P) fertilizers. Importance and impact of waste water in agriculture and related activities is discussed in detail (Energy Transport and Water Department, Water Anchor (ETWWA) 2010; Hussain et al. 2002; Kaur et al. 2012). However, suitable treatment mechanism of waste water is very much essential before implementing the same in the real world planning problems from sustainable point of view.

Annual water requirement of Pune city for domestic purposes is 275.16 Mm^3 and that of Pimpri-Chinchwad is 185 Mm^3 . Pune city generates around 451 Million Liter per Day (MLD) of sewage. Pimpri-Chinchwad city generates 287 MLD of sewage (Tirthkar 2009). Both corporations are expected to treat total of 265 Mm^3 waste water per annum; through different treatment units. The mathematical model considers 20.49 Mm^3 of treated waste water per month i.e. 245.88 Mm^3 per year. At present, 68 % of the total sewage generated by Pune Municipal Corporation (PMC) and 63 % sewage generated by Pimpri-Chinchwad Municipal Corporation (PCMC) is treated before being discharged into the rivers. PMC and PCMC under the master plan will treat 100 % of its sewage generated by the end of 2015. Municipal authorities are abiding by the norms of State Pollution

Control Board for disposal of treated sewage into the rivers (Manual on Sewerage and Sewage Treatment 1993).

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 and Pavana rivers, flowing through Pune and Pimpri-Chinchwad city. The city development being along the banks of rivers, the existing sewerage system carries the sewage by gravity upto the treatment plants, located near the river banks. As far as possible natural land contours are used to avoid pumping of sewage. One hundred eighty four Mm³ of treated waste water is proposed to be lifted in NMRBC at suitable location downstream of Pune city for the additional command of JSLIS. Pumping of water into the canal system is unavoidable as the canal is flowing along higher contours. Part of remaining waste water flowing through river along with monsoon spills from Khadawasla dam is used for PLIS command development. The cost of treated waste water pumping into the NMRBC is not considered in the model because it is a condition laid by irrigation department, while sanctioning additional water demand of Pune Municipal Corporation; that the PMC will pump treated waste water into the existing NMRBC at suitable location downstream of Pune city at their cost. Mathematical model developed in subsequent section considers this aspect of the project.

4 Mathematical Modeling

4.1 Objective Functions

Three objectives are considered in the present study. The first objective of the model is to maximize the Net Benefits (NB) from the Khadakwasla, JSLIS and PLIS, after meeting the cost of groundwater. The net benefit includes irrigation benefit, revenue generated from domestic water supply to PMC and water supplied to industries. In the present study even though drinking water and water supplied to industry are fixed, these are shown as variables in objective function so that model is more generalized.

Net benefits from the crops per hectare are worked out based on the practice followed by the office of Divisional Joint Director of Agriculture, Pune Division, Pune. Crop yield is taken as per the agriculture department record for the Pune district. Calculations extensively covers the aspect of post harvesting practices, Fodder receipt, Dung receipt, Seed cost, Fertilizer cost, Pesticide cost, expenditure on Fodder, Implant, Labour charges, Irrigation charges, Working charges and interest on capital etc. All the relevant information is obtained from reports, secondary sources and interactions with subject experts from Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra. Cost of groundwater was fixed based on the discussions with farmers and local pump supply dealers, views of officials. In addition initial cost, fixed electricity charges, operation and maintenance cost, interest on capital and depreciation was also considered as basis while working out cost of groundwater pumping. The cost of irrigation water, domestic water supplied to Pune city and industry water is taken as per actual rates charged to users by the irrigation department, Government of Maharashtra, India.

Net Benefit is expressed (in Rs.) as

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

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

$$PD = \sum_{i=1}^{36} PD_i A_i \quad (2)$$

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:

$$LE = \sum_{i=1}^{36} LE_i A_i \quad (3)$$

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, $t=1, \dots, 12$; (1 = June, ..., 12 = May); P_{GW} = Cost of groundwater pumping (Rs./Mm³); P_{DW} , P_{IND} = Revenue from drinking water (domestic water supply) and industrial water supply respectively (Rs./Mm³); A_i = Area of the crop i ; B_i = Return from crop i (Rs./ha); GW_t , DW_t , IND_t = Groundwater, Domestic and industrial water supply in Mm³ for the month t ; PD_i = Production of crop i (ton/ha); LE_i = Labour employment of crop i (man-days/ha).

4.2 Constraints

4.2.1 Continuity Equation

The Khadakwasla reservoir is operated on monthly basis, with the inflows from upper storage reservoirs (Fig. 2). A time series of monthly inflow data for 31 years from 1976–77 to 2006–07 is available. Dependable inflows have been worked out using percentage probability of the inflow magnitude being equaled or exceeded by the respective value. Weibull plotting position formulae is used for this purpose. 75 % dependable values of monthly inflows for June to May (in Mm³) are 43.58, 135.97, 161.25, 69.27, 24.19, 29.48, 46.77, 44.95, 39.39, 41.59, 47.42, and 53.04.

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

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

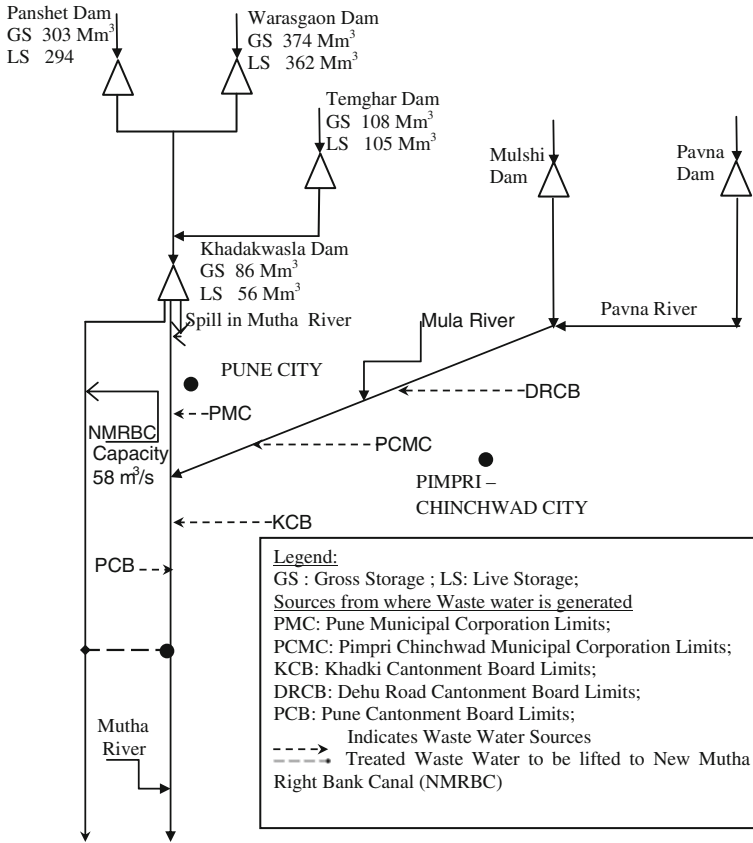


Fig. 2 Schematic diagram of case study

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 Mm³.

4.2.2 Land Requirement of Crops

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

4.2.3 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.

Khadakwasla Project

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

where WW = Waste water utilized by Khadakwasla and JSLIS combine during month t ; CWR_{it} = Water requirement of crop i during t^{th} month. Monthly gross irrigation demands of Khadakwasla command for June to May (in mm per ha of command area) are; 1234, 1400, 1728, 827, 602, 605, 636, 579, 454, 642, 828 and 600 respectively.

Groundwater potential in command area is estimated by the Groundwater Survey and Development Agency (GSDA). In the present study, monthly groundwater availability GW_t of 10 Mm^3 is taken into consideration based on the information provided by GSDA, Pune as published in their report. (Net GroundWater Availability for Future Irrigation use, Pune 2008).

JSLIS Eighty five percent of the water supplied to the city for domestic and industrial purposes i.e., $20.49 \text{ Mm}^3/\text{month}$ 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 (Fig. 2.).

Pune city is growing by leaps and bounds in all directions. This urbanization has resulted in reduction of irrigation requirements/demands in distributaries 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 Eqs. (5) and (6).

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

Monthly gross irrigation demands of JSLIS command for June to May (in mm per ha of command area) are; 1296, 1252, 1550, 1000, 731, 451, 463, 392, 386, 560, 722, and 534 respectively.

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 Eq. (7).

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

Monthly gross irrigation demands of PLIS command for June to May (in mm per ha of command area) are; 589, 1026, 1336, 802, 682, 462, 555, 455, 343, 569, 820, and 1000 respectively.

4.2.4 Canal Capacity

Irrigation releases from Khadakwasla reservoir cannot exceed the NMRBC capacity CC_t . Here CC_t is converted into volumetric units i.e., Mm^3 .

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

Other constraints that are used in the present study are minimum and maximum reservoir storages, minimum and maximum command area restrictions, spill over the spillway. Fixed monthly demands of drinking water and industrial water, average monthly evaporation losses, maximum monthly groundwater potential ($10 Mm^3$) are treated as bounds in the model.

5 Fuzzy Multiobjective Optimization Modeling Approaches

In the present study it is assumed that objectives 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). For example, there will be variation in market prices of crops which influences the benefits. Productivity of a particular crop over the years may vary on account of availability of water, change in climate, availability of fertilizers, adopting better farming practices. Similarly, labour employability on account of advances in farming techniques is also likely to vary. These uncertain changes in the parameters of the three objective functions are assumed to be represented by the three membership functions, namely, Nonlinear, Hyperbolic and Exponential. Mathematical formulations of three membership functions are explained in detail only for maximization situations (as all three chosen objectives are maximization in nature).

5.1 Nonlinear Membership Function

Nonlinear membership function for any objective function Z can be expressed as (Fig. 3(a)):

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

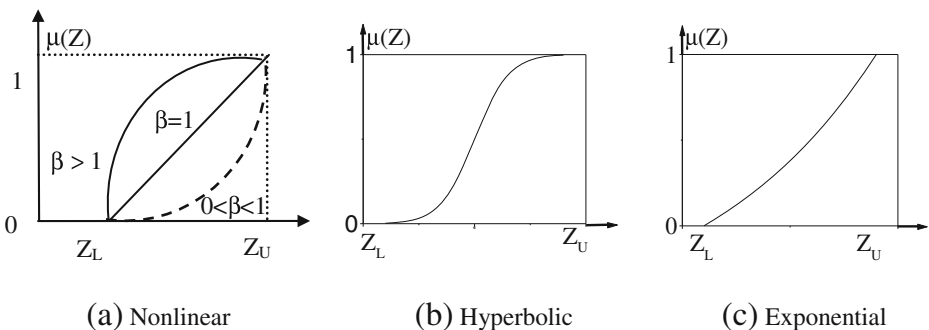


Fig. 3 Membership functions in maximization scenario

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 ($\beta=1$ for linear; $\beta>1$ and $\beta<1$ for nonlinear) (Sasikumar and Mujumdar 1998).

Introducing a new variable λ , the problem can be reorganized as

Maximize λ

Subject to

$$[\mu_{G_j}(X)]^\beta \geq \lambda \text{ for each objective function } j=1,2,\dots,n$$

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

and all other existing constraints and bounds. Here μ_{G_j} represents the membership functions for objective.

5.2 Hyperbolic Membership Function

Hyperbolic membership function for any objective of maximization in nature can be expressed as (Bit et al. 1992; Kagade and Bajaj 2009; Rani and Moreira 2010) (Fig. 3(b))

$$\mu_Z(X) = \begin{cases} 0 & \text{for } Z \leq Z_L \\ \frac{1}{2} \tanh \left[\left(Z - \frac{Z_U + Z_L}{2} \right) \alpha_p \right] + \frac{1}{2} & \text{for } Z_L < Z < Z_U \\ 1 & \text{for } Z \geq Z_U \end{cases} \quad (10)$$

here α_p is parameter defined as $\frac{6}{Z_U - Z_L}$

It is further simplified by introducing new variable $U = \tanh^{-1}(2\lambda - 1)$ with λ as degree of satisfaction. The equivalent crisp model for fuzzy modeling can be formulated as

Maximize U

Subject to

$$\begin{aligned} Z\alpha_p - \frac{\alpha_p}{2}(Z_U - Z_L) &\geq U \\ 0 &\leq U \leq 1 \end{aligned} \quad (11)$$

with all other existing constraints and bounds.

5.3 Exponential Membership Function

An exponential membership function for any objective of maximization in nature can be expressed as: (Fig. 3(c))

$$\mu_Z(X) = \begin{cases} 0 & \text{for } Z \leq Z_L \\ \frac{e^{-S\Psi_p(X)} - e^{-S}}{1 - e^{-S}} & \text{for } Z_L < Z < Z_U \\ 1 & \text{for } Z \geq Z_U \end{cases} \quad (12)$$

Where,

$$\Psi_p(X) = \frac{Z_U - Z}{Z_U - Z_L} \quad (13)$$

S is a nonzero parameter ($0 < S \leq 1$), prescribed by the decision maker. The equivalent crisp model for the fuzzy model can be formulated as:

Maximize λ
 Subject to

$$\frac{e^{-S\Psi_p(X)} - e^{-S}}{1 - e^{-S}} \geq \lambda \quad (14)$$

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

and all other existing constraints and bounds.

6 Results and Discussion

The model developed has three objectives, 141 constraints and 136 variables. Initially the model is solved independently using Language for Interactive General Optimization (LINGO; <http://www.lindo.com>) software for three objectives NB, PD and LE to define upper and lower limits of the objectives. These are used as the basis while formulating nonlinear, hyperbolic and exponential fuzzy membership function. (refer Eqs. 9, 10 and 12; Fig. 3.).

6.1 Fuzzy Objectives and Dependable Inflows

The objective of the present study is to investigate the applicability of Multiobjective Fuzzy Programming technique with nonlinear, hyperbolic and exponential membership functions for three objectives. In the present study 75 % dependable inflow scenario which represents general water resources planning problem in India is considered (Maji and Heady 1980). In addition conjunctive use concept is also explored.

In case of nonlinear membership function, the three objectives are evaluated with $\beta_1=1$ (exponent for Labour Employment), $\beta_2=1.8$ (exponent for Crop Production equation), $\beta_3=0.7$ (exponent for Net Benefits). The values of β_1 , β_2 , β_3 are chosen randomly to explore suitability of the method.

Solution of the multiobjective model gives compromise cropping pattern, monthly storage policy, monthly release policy and monthly use of waste water as well as groundwater. Table 2 presents degree of satisfaction, net benefits, crop production, labour employment and irrigation intensity aspects for each membership situation. Table 3 presents monthly reservoir operation, release, waste water use and groundwater use policy (with and without groundwater). Table 4 presents monthly release and waste water use for JSLIS command whereas Table 5 presents monthly reservoir spills and waste water use for PLIS command.

It is observed from Table 2 that for the case with groundwater, the maximum net benefit of Rs. 2296.757×10^6 is recorded for exponential membership function, maximum Crop Production of 2400777 ton with nonlinear membership function whereas maximum Labour employment of 7952016 man days is generated in hyperbolic membership function case with groundwater. These values when compared to without groundwater scenario, indicate increase of 16.06 % in net benefits, 11.90 % in crop production and 16.71 % in labour employment. However, both hyperbolic and exponential membership functions yield same values as evident from Table 2.

Table 2 gives values of degree of satisfaction (λ) for all the cases explored. The λ value represents degree of association within the conflicting objectives, thus representing the compatibility amongst the objectives. It is observed that the λ value increases from 0.58 to 0.82 (NL: with GW to without GW), 0.79 to 0.98 (Hyperbolic: with GW to without GW) and 0.49 to 0.74 (Exponential: with GW to without GW).

Table 2 Multiobjective fuzzy nonlinear solutions for 75 % dependable inflow scenario

Salient parameters	Fuzzy membership function for					
	With groundwater			Without groundwater		
	Nonlinear (NL) $\beta_1=1, \beta_2=1.8, \beta_3=0.7$	Hyperbolic	Exponential	Nonlinear $\beta_1=1, \beta_2=1.8, \beta_3=0.7$	Hyperbolic	Exponential
Degree of satisfaction (λ)	0.58	0.79	0.49	0.82	0.98	0.74
Net benefit (10^6 Rs.)	2272.223	2296.754	2296.757	1967.662	1978.885	1978.840
Net Crop Production (10^3 ton)	2400.777	2365.184	2365.190	2145.422	2127.030	2127.032
Labour employment (10^3 Man days)	7930.458	7952.016	7952.006	6811.662	6813.262	6816.249
Project	Irrigation intensity (%) and increase/decrease in irrigation intensity					
Existing (%)						
Khadakwasla	66.5(+5.5)	66.44(+5.4)	66.44(+5.4)	62.3(+1.3)	62.28 (+1.28)	62.28 (+1.28)
JSLIS	100(+29.00)	99.59 (+28.6)	99.59 (+28.6)	97.16(+26.16)	95.74(+24.74)	95.74(+24.74)
PLIS	81.69(+18.69)	83.44 (+20.4)	83.44 (+20.4)	61.53(-1.47)	63.28(+0.28)	63.28(+0.28)

Conversion rate for US\$ to Rs as on 15 April 2013 is 1 US \$=54.62 Indian Rs

Table 3 Reservoir operation policy, release policy, waste water (WW) use and groundwater (GW) use for Khadakwasla command for 75 % dependable inflow scenario (Mm³)

Month	NL membership function			Hyperbolic membership function			Exponential membership function					
	Reservoir storage	Reservoir releases	WW use	GW use	Reservoir storage	Reservoir releases	WW use	GW use	Reservoir storage	Reservoir releases	WW use	GW use
75 % dependable inflow with GW												
Jan	0.00	18.39	6.11	10.00	0.00	19.04	6.11	8.50	0.00	19.04	6.11	8.50
Feb	0.65	9.05	4.22	10.00	0.00	8.11	4.22	10.00	0.00	9.05	4.22	9.06
Mar	5.23	15.81	4.24	10.00	5.52	15.56	4.24	8.95	4.58	15.03	4.24	9.47
Apr	5.10	24.12	3.16	10.00	5.64	24.21	2.71	9.06	5.23	23.79	2.71	9.47
May	0.00	12.56	1.39	10.00	0.00	11.91	0.65	10.00	0.00	11.91	0.65	10.00
Jun	13.11	18.70	5.05	10.00	13.04	18.63	4.69	10.00	13.04	18.63	4.69	10.00
Jul	8.56	43.98	0.00	10.00	8.58	43.74	0.00	10.00	8.58	40.28	3.47	10.00
Aug	56.00	89.71	0.00	0.00	56.00	89.47	0.00	0.00	56.00	89.47	0.00	0.00
Sep	56.00	28.19	0.00	3.78	56.00	28.17	0.00	3.62	56.00	28.17	0.00	3.62
Oct	56.00	16.19	2.74	10.00	56.00	15.73	2.40	10.00	56.00	15.73	2.40	10.00
Nov	29.97	21.43	7.16	10.00	30.09	21.03	6.77	10.00	30.09	21.03	6.77	10.00
Dec	8.36	23.55	6.55	10.00	4.84	23.23	6.10	10.00	8.48	23.23	6.10	10.00
Annual use		321.68	40.62	103.78		318.82	37.89	100.13		315.35	41.36	100.13
75 % dependable inflow without GW												
Jan	5.45	24.49	6.11	0.00	5.47	24.51	6.11	0.00	5.47	24.51	6.11	0.00
Feb	0.00	13.25	4.22	0.00	0.00	13.32	4.22	0.00	0.00	13.32	4.22	0.00
Mar	0.38	15.28	4.24	0.00	0.31	15.48	4.24	0.00	0.31	15.48	4.24	0.00
Apr	0.78	21.42	4.78	0.00	0.52	21.59	5.23	0.00	0.50	21.59	5.23	0.00
May	0.00	14.92	2.87	0.00	0.00	15.73	2.87	0.00	0.00	15.73	2.87	0.00
Jun	12.24	29.96	8.31	0.00	11.43	29.15	7.96	0.00	11.43	29.15	7.96	0.00
Jul	0.00	55.28	0.00	0.00	0.00	54.64	0.00	0.00	0.00	54.65	0.00	0.00
Aug	44.14	77.76	9.98	0.00	44.91	86.84	0.00	0.00	44.91	86.84	0.00	0.00

Table 3 (continued)

Month	NL membership function			Hyperbolic membership function			Exponential membership function					
	Reservoir storage	Reservoir releases	WW use	GW use	Reservoir storage	Reservoir releases	WW use	GW use	Reservoir storage	Reservoir releases	WW use	GW use
Sep	56.00	25.36	3.04	0.00	56.00	27.87	0.00	0.00	56.00	27.87	0.00	0.00
Oct	56.00	11.04	5.36	0.00	56.00	11.33	5.07	0.00	56.00	11.33	5.07	0.00
Nov	38.58	22.32	8.39	0.00	38.17	22.21	8.50	0.00	38.17	22.21	8.50	0.00
Dec	17.65	28.88	8.04	0.00	17.45	28.77	8.15	0.00	17.45	28.77	8.15	0.00
Annual use		339.96	65.35	0.00		351.44	52.35	0.00		351.45	52.35	0.00

Table 4 Reservoir release policy, waste water (WW) use for JSLJIS command for 75 % dependable inflow scenario (Mm³)

Month	75 % dependable inflow with GW						75 % dependable inflow without GW					
	NL		Hyperbolic		Exponential		NL		Hyperbolic		Exponential	
	Reservoir releases	WW use	Reservoir releases	WW use	Reservoir releases	WW use	Reservoir releases	WW use	Reservoir releases	WW use	Reservoir releases	WW use
Jan	0.00	6.11	0.00	6.11	0.00	6.11	0.00	6.11	0.00	6.11	0.00	6.11
Feb	0.00	4.22	0.00	4.22	0.00	4.22	0.00	4.22	0.00	4.22	0.00	4.22
Mar	0.00	4.24	0.00	4.24	0.00	4.24	0.00	4.24	0.00	4.24	0.00	4.24
Apr	2.54	3.16	2.99	2.71	2.99	2.71	0.92	4.78	0.48	5.23	0.48	5.23
May	1.48	1.39	2.22	0.65	2.22	0.65	0.00	2.87	0.00	2.87	0.00	2.87
Jun	3.58	5.05	3.55	4.69	3.55	4.69	0.00	8.31	0.00	7.96	0.00	7.96
Jul	10.71	0.00	10.41	0.00	6.39	3.47	10.40	0.00	10.26	0.00	10.27	0.00
Aug	15.58	0.00	15.24	0.00	15.24	0.00	4.76	9.98	14.34	0.00	14.34	0.00
Sep	12.42	0.00	12.27	0.00	12.27	0.00	8.75	3.04	11.50	0.00	11.50	0.00
Oct	7.39	2.74	7.74	2.40	7.74	2.40	3.94	5.36	4.07	5.07	4.07	5.07
Nov	3.49	7.16	3.88	6.77	3.88	6.77	1.91	8.39	1.80	8.50	1.80	8.50
Dec	5.56	6.55	6.00	6.10	6.00	6.10	4.07	8.04	3.96	8.15	3.96	8.15
Annual use	62.75	40.62	64.30	37.89	60.28	41.36	34.75	65.34	46.41	52.35	46.41	52.35

Table 5 Reservoir spills and waste water (WW) use for PLIS command for 75 % dependable inflow scenario (Mm³)

Month	75 % dependable inflow with GW						75 % dependable inflow without GW					
	NL		Hyperbolic		Exponential		NL		Hyperbolic		Exponential	
	Spill	WW use	Spill	WW use	Spill	WW use	Spill	WW use	Spill	WW use	Spill	WW use
Jan	0.00	8.27	0.00	8.27	0.00	8.27	0.00	8.27	0.00	8.27	0.00	8.27
Feb	0.00	12.06	0.00	12.06	0.00	12.06	0.00	12.06	0.00	12.06	0.00	12.06
Mar	0.00	12.01	0.00	12.01	0.00	12.01	0.00	12.01	0.00	12.01	0.00	12.01
Apr	0.00	14.16	0.00	15.07	0.00	15.07	0.00	10.92	0.00	10.03	0.00	10.03
May	0.00	17.72	0.00	19.18	0.00	19.18	0.00	14.75	0.00	14.75	0.00	14.75
Jun	0.00	10.39	0.00	11.11	0.00	11.11	0.00	3.86	0.00	4.56	0.00	4.56
Jul	7.71	20.49	8.25	20.49	15.19	13.55	0.00	20.49	0.00	20.49	0.00	20.49
Aug	29.52	20.49	30.12	20.49	30.12	20.49	40.45	0.53	22.56	20.49	22.56	20.49
Sep	2.03	20.49	2.21	20.49	2.21	20.49	8.54	14.42	3.28	20.49	3.28	20.49
Oct	0.00	15.00	0.00	15.69	0.00	15.69	0.00	9.76	0.00	10.34	0.00	10.34
Nov	0.00	6.17	0.00	6.95	0.00	6.95	0.00	3.70	0.00	3.49	0.00	3.49
Dec	0.00	7.39	0.00	8.28	0.00	8.28	0.00	4.41	0.00	4.19	0.00	4.19
Annual use	39.26	164.64	40.58	170.09	47.52	163.15	48.99	115.17	25.84	141.17	25.84	141.18

Irrigation intensity of Khadakwasla project in case of nonlinear membership function solutions, increases by 5.5 % with groundwater and 1.3 % without groundwater. The same is observed to increase by 29 % and 26.16 % for JSLIS. It increases by 18.69 % with groundwater for PLIS and decreases marginally by 1.47 % without groundwater scenario. In case of exponential/hyperbolic functions, irrigation intensity increases by 5.4 % with groundwater and 1.28 % without groundwater in case of Khadakwasla. The same is observed to increase by 28.6 % and 24.74 % for JSLIS. It increases by 20.4 % with groundwater for PLIS and increases by 0.28 % without groundwater scenario.

Irrigation intensity in general in all cases with GW and without GW is more than existing irrigation intensity. However, irrigation intensity with GW is more than without GW which indicates that impact of GW is significant and should be explored as sufficient groundwater resources are available. Thus it can be concluded that overall the irrigation intensity is increasing in comparison with existing crop pattern almost for all commands with each membership function.

6.2 Cropping Pattern

Comparative analysis of Khadakwasla cropping pattern (with and without GW scenario) suggests that there is increase in LS Cotton (48.92 %), Paddy drilled (45.33 %); while it shows decrease in area of Chillies (94 %), Groundnut(HW) (38.94 %) and Sugarcane (68.84 %) (refer Fig. 4a and b). This may affect economy of the region as there are many sugar industries located within the command. These sugar industries use the sugarcane produced by the local farmers, who are also shareholders of the cooperatively run sugar industries. Hence in given situation, groundwater use is inevitable. In case of JSLIS, no change in existing crop areas of Hybrid Jowar (R) and Paddy (TP) is observed. Rest all crops

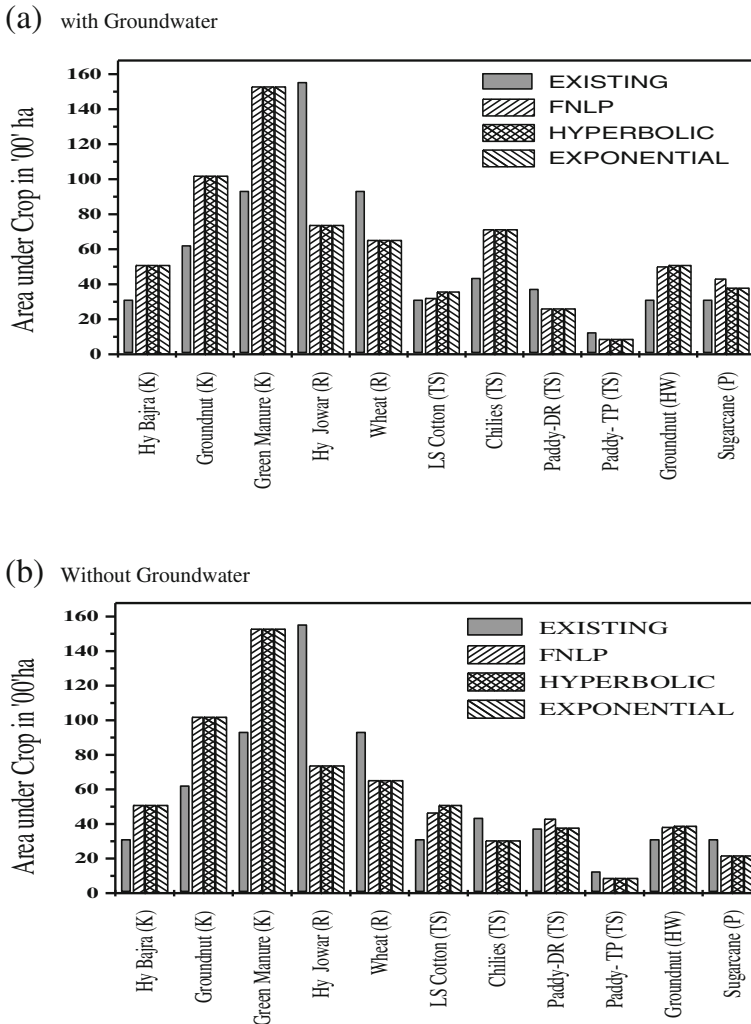


Fig. 4 Cropping pattern in Khadakwasla for 75 % dependable inflows and fuzzy objectives

indicates maximum of 41 % increase in area. Without GW case, there is decrease in area of Groundnut (K) (17.61 %) and Chillies (K) (40.95 %). JSLIS crop pattern suggests considerable improvement over existing crop pattern. In case of PLIS, 60 % increase in area under Green Fodder (K), Onion (K), Pulses (K), Fodder (K), and Vegetables (HW) is observed. In without GW case, area under Hybrid Bajra (K) is observed to reduce by 51.95 % and that for Groundnut (K) it reduces by 129.96 %. Similarly for Vegetable (K) (38.53 %), Tur (Pigeon pea) (K) (130.01 %), Gram(R) (22.75 %), Fruit (P) (80.80 %), Sugarcane (P) (86.99 %).

6.3 Reservoir Storages

Table 3 presents the storage policy for Khadakwasla reservoir. It is observed that monthly reservoir storages are almost same in nonlinear, hyperbolic and exponential membership

environment. It is also observed that maximum storage (56 Mm^3) has reached in the month of August, September and October whereas zero storage is observed in the month of January and May in case of with GW use in all three membership functions. It is also observed that Storage in February is 0.65 Mm^3 , 0, 0 respectively for nonlinear, hyperbolic and exponential membership environment. In case of without GW use, maximum storage has reached in the month of September and October and zero storage is observed in the month of February, May and July.

6.4 Reservoir Releases

Tables 3 and 4 presents monthly irrigation release policy for the Khadakwasla and JSLIS command. Annual irrigation releases for Khadakwasla command are observed to vary marginally in case of 75 % dependable inflow with GW. The annual releases are 321.68 Mm^3 (NL), 318.82 Mm^3 (Hyperbolic) and 315.35 Mm^3 (Exponential). Corresponding annual irrigation releases for the case of 75 % dependable inflow without GW are 339.96 Mm^3 (NL), 351.44 Mm^3 (Hyperbolic) and 351.45 Mm^3 (Exponential). This indicates that if GW is not utilized, the reservoir releases are increased by 5.37 % (NL), 9.28 % (Hyperbolic), and 10.27 % (Exponential). Irrigation releases for JSLIS during the month of Jan, Feb and Mar are observed to be zero in all three cases of with GW and without GW. Reservoir releases for NL, Hyperbolic and Exponential membership environments are 62.75, 64.30, 60.28 Mm^3 (in case of with GW use) and these are 34.75, 46.41, 46.41 respectively in case of without GW use.

6.5 Groundwater Utilization

The annual groundwater use by Khadakwasla command for the case of nonlinear, hyperbolic and exponential membership function is 103.78, 100.13 and 100.13 Mm^3 respectively (Table 3). Groundwater use is observed to be zero during the month of Aug in all cases, as there is availability of irrigation releases during the same month, augmented by rainfall.

6.6 Waste Water Utilization

Tables 3, 4 and 5 gives monthly use of treated waste water for Khadakwasla, JSLIS and PLIS command. It is observed in general for cases with GW, that JSLIS and Khadakwasla commands utilize 32.50 % of available waste water to supplement its need, while PLIS uses 67.5 % of the available waste water. Waste water utilization in similar cases without GW is 46.11 % for JSLIS and Khadakwasla command and 53.89 % for PLIS. It is also observed from Khadakwasla scenario that waste water reuse in case of without GW is more than with GW as evident from Table 3.

The model is so formed that the waste water and spill if any, will cater for the demands of PLIS command. Table 2 indicates that there is a definite increase in command area of JSLIS and PLIS. This increase can be definitely attributed to the use of recycled waste water. Though recycled waste water is not explicitly considered in the objective function; some percent of the benefits generated out of use of recycled waste water could be given back to the PMC/PCMC for maintaining the sewage treatment plant sustainably. The sewage treatment plant can be augmented with more sophisticated instrumentation and infrastructure, so that later, even this water can be utilized for domestic water supply, which will reduce the stress on the fresh water significantly.

Overall it may be concluded that there cannot be inter se comparison of λ values with different membership functions; as the three membership functions are represented by

different mathematical relationships. It can only be compared within a membership function for given set of conditions. In addition, from the observed results and inferences drawn, hyperbolic and exponential membership functions can be explored further as there is no parameter requirement such as β in case of nonlinear membership function which may be required for extensive sensitivity analysis before narrowing down to suitable sets of β values for each objective. As far as author's knowledge (along with supporting literature review) is concerned, it is the first application where multiobjective fuzzy programming is explored with three membership functions, nonlinear, hyperbolic and exponential to a case study of multireservoir system with Integrated Sustainable Water Resources Management as the focus.

6.7 Sensitivity Analysis

Extensive sensitivity analysis is performed for nonlinear membership function situation to understand the effect of β values on the net benefit, crop production and labour employment and relevant parameters. However, no sensitivity analysis is performed for hyperbolic and exponential functions as there is no such parameter which is affecting the outcome as compared to β values. Present study evaluated thirty six combinations (12 for each scenario) which are as follows:

- Scenario 1: $\beta_2 = \beta_3 = 1$, i.e. linear and $\beta_1 =$ nonlinear related to labour employment [0.1, 0.4, 0.7, 0.9, 1.5, 1.8, 2.3, 2.9, 3.5, 4.5, 5, and 7]
- Scenario 2: $\beta_3 = \beta_1 = 1$, i.e. linear and $\beta_2 =$ nonlinear related to crop production [0.1, 0.4, 0.7, 0.9, 1.5, 1.8, 2.3, 2.9, 3.5, 4.5, 5, and 7]
- Scenario 3: $\beta_1 = \beta_2 = 1$, i.e. linear and $\beta_3 =$ nonlinear related to Net Benefits [0.1, 0.4, 0.7, 0.9, 1.5, 1.8, 2.3, 2.9, 3.5, 4.5, 5, and 7]

Typical results for the scenario 3 (with groundwater), where exponent of membership function for Net Benefits (β_3) is varying are presented in Table 6 and Fig. 5. The overall intensity of irrigation in this case was observed to be varying between 72.98 % and 74.74 % with $\beta_3 < 1$ and it decreases with increase in β_3 beyond 1 from 74.60 % to 74.27 %. Degree of satisfaction is decreasing from 0.75 to 0.53 with increase in β_3 value from 0.1 to 7. For $\beta_3 < 1$, it is observed that as β increases λ , PD and LE values are decreasing linearly, while the value of NB is increasing nonlinearly. Similar trend is observed in case of $\beta_3 > 1$. Variation of any one of exponent β_1 or β_2 or β_3 has influence on all the three objective function values. If we increase exponent β_1 , the value of objective function corresponding to β_1 (Max Labour Employment) will increase and the other two objective function values will decrease. Therefore it is concluded that keeping exponent value of β_1 and β_2 constant and using higher values of exponent β_3 , will always give increased net benefits with lesser degree of satisfaction in compromise solution for multiobjective scenario. When irrigation managers are uncertain about the exponent ' β ' of membership function representing the objectives, hyperbolic membership function can be used, which will give higher benefit values in compromise solution for multiobjective scenario. Exponential membership function is avoided as it has a nonzero parameter ($0 < S \leq 1$), to be prescribed by the decision maker.

7 Summary and Conclusions

Multiobjective Fuzzy Nonlinear, Hyperbolic and Exponential membership functions are applied to solve a case study of Khadakwasla complex irrigation project located near Pune

Table 6 Sensitivity analysis: fuzzy nonlinear membership function: variation of (β_3) in case of 75 % dependable inflow with GW

Characteristics	$\beta_1 = \beta_2 = 1$											
	$\beta_3=0.1$	$\beta_3=0.4$	$\beta_3=0.7$	$\beta_3=0.9$	$\beta_3=1.5$	$\beta_3=1.8$	$\beta_3=2.3$	$\beta_3=2.9$	$\beta_3=3.5$	$\beta_3=4.5$	$\beta_3=5$	$\beta_3=7$
Area under crop in Khadakwasla ("100"ha)	720.66	720.85	720.07	676.39	672.86	671.90	671.47	671.11	670.86	670.56	670.45	670.14
Intensity of irrigation in %	70.87	70.89	70.81	66.52	66.17	66.07	66.03	66.00	65.97	65.94	65.93	65.90
Area under crop in JSLIS ("100"ha)	197.40	197.40	197.40	196.25	196.25	196.25	196.25	196.25	196.25	195.83	195.48	194.52
Intensity of irrigation in %	100.18	100.18	100.18	99.59	99.59	99.59	99.59	99.59	99.59	99.38	99.20	98.71
Area under crop in Purandar ("100" ha)	271.60	264.86	261.59	334.80	336.14	336.40	335.73	335.18	334.78	334.70	334.84	335.23
Intensity of irrigation in %	67.63	65.95	65.14	83.37	83.70	83.76	83.60	83.46	83.36	83.34	83.38	83.47
Total area under crop ("100"ha)	1189.67	1183.12	1179.06	1207.44	1205.25	1204.54	1203.45	1202.54	1201.89	1201.09	1200.77	1199.89
Over all intensity of irrigation in %	73.64	73.23	72.98	74.74	74.60	74.56	74.49	74.44	74.40	74.35	74.33	74.27
Net benefit in 'Millian Rs'	2212.45	2260.36	2282.64	2292.41	2311.92	2317.82	2324.60	2330.241	2334.275	2338.872	2340.549	2345.155
Crop production in 'Metric Ton'	2402285	2385211	2372032	2366661	2360020	2357856	2354350	2351426	2349334	2346536	2345323	2341990
Labour employment in 'Man Days'	8042602	8000913	7968735	7955622	7939407	7934125	7925564	7918425	7913316	7906485	7903522	7895385
Degree of satisfaction ' λ '	0.75	0.69	0.64	0.62	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.53

Conversion rate for US\$ to Rs as on 15 April 2013 is 1 US \$=54.62 Indian Rs

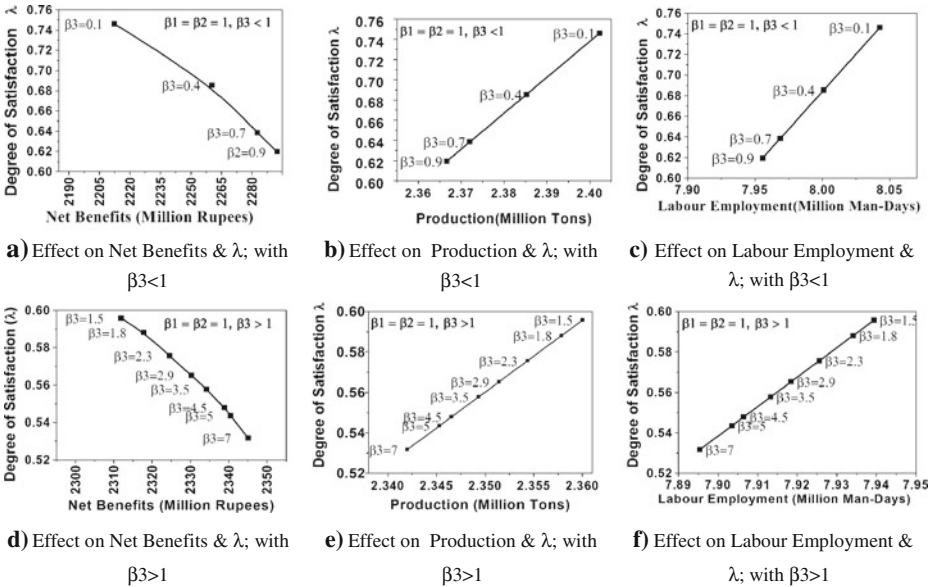


Fig. 5 Sensitivity analysis: effect of variation of ‘ β_3 ’ on values of objective function and degree of satisfaction ‘ λ ’ for 75 % dependable inflow with GW scenario

city of Maharashtra State, India. The present study helped to analyze the complex situation, together for canal irrigation and lift irrigation with clear social objective of serving the people in higher reaches of command with precarious water for their farms. This also paves the way for realistic implementation of the proposed methodology. Maximization of net benefits, crop production and labour employment are considered along with waste water reuse and dependable inflow scenario. The following conclusions are drawn from the present study:

1. It is concluded that exponential and hyperbolic membership functions provided similar cropping pattern in most of the situations whereas nonlinear membership function provided different cropping pattern. Nonlinear membership function has an additional scope to explore various scenarios by varying exponent values. The exponent values can be decided based on past data available on various related parameters in objective function and the curve fitting within those values.
2. Proposed irrigation intensity is more than the existing irrigation intensity for all the membership environments with and without groundwater.
3. The waste water generated by the Pune city and Pimpri-Chinchwad city can be reutilized after suitable treatment which effectively contributes to improve the cropping pattern and to increase the command. This also reduces the fresh water demand, thus further reducing the stress on surface and groundwater requirement. Efforts should be taken to ensure 100 % treatment of waste water for possible recycling
4. Provide water if available, through lift Irrigation schemes, while ensuring the revenue collection at higher rates. This may need a social campaign of awareness of water costs and water pricing.
5. It may be concluded that there cannot be inter se comparison of λ values with different membership functions.
6. Variation of any one of exponent β_1 or β_2 or β_3 has influence on all the three objective function values.

7. Integrated Sustainable Water Resources Management of existing irrigation projects would help extending project benefits to larger section of society and effective utilization of available water resources.

Acknowledgments Authors are grateful to Superintending Engineer and Executive Engineer of Khadakwasla Irrigation Project, for providing the data on Khadakwasla Project; Director, Groundwater Surveys and Development Agency, Pune for providing groundwater potential in Khadakwasla command; Divisional Joint Director, Agriculture, Pune, Division, for providing input on crop yield, crop pattern, crop prices; Executive Engineer, Minor Irrigation Div., Sub Div.1 for providing practical inputs of PLIS. Acknowledgements are due to Authorities at Mahatma Phule Krishi Vidyapeeth, Rahuri, (An Agricultural University) for providing most practical inputs on cost of cultivations for the region and cropping pattern, economics of agriculture.

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