OPTIMAL RESERVOIR OPERATION POLICY DETERMINATION FOR UNCERTAINTY CONDITIONS

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ABSTRACT

In recent years, optimising reservoir operations has emerged as a hot topic in the field of water resources management. Heuristic approaches to reservoir operation that incorporate rule curves and, to some extent, operator discretion have been the norm in the past. With so many stakeholders involved in water management, it can be difficult to strike a happy medium between everyone's needs and wants. The dissertation proposes a method for transforming traditional reservoir operation into optimal strategies, allowing users to take advantage of the rapid development of computational techniques.

This research creates and applies a Multi Objective Fuzzy Linear Programming (MOFLP) model to the monthly operating policies of the stage-I Jayakwadi reservoir located on the Godavari, the largest river in the Indian state of Maharashtra. In order to formulate the problem, we use two objective functions—maximizing irrigation releases and maximising power production releases. The constraints of the study are considered, including turbine release, irrigation demand, reservoir storage capacity, and continuity of reservoir storage. Utilizing linear membership functions, the objective functions are fuzzily defined. All other model parameters except for the goals are assumed to be hard and fast rules. Maximum Happiness Operating Policy (MOFLP) was used to determine the best course of action.

KEYWORDS

Jayakwadi Reservoir, Fuzzy Set Theory, Linear Programming, Irrigation.

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1. INTRODUCTION

The system engineering method for the water resources system employs a schematic analysis of the numerous alternatives available to policy and decision makers. Each option presents a complex problem with entangled effects, necessitating not only the consideration of a much larger number of alternatives but also the analysis of each option in light of its impacts at a number of locations. The system engineering method offers a flexible platform for constant assessment and re-planning in the face of unforeseen circumstances. When applied with an understanding of its limitations, this strategy has the potential to greatly enhance the management of water resource systems. The advent of digital computers has allowed for the efficient examination of problems for mathematical solutions and the management of vast amounts of data. Linear programming, dynamic programming, goal programming, integer programming, simulation techniques, etc. are all examples of system engineering approaches that find use in the water resources industry. However, there is no one solution that works for every conceivable problem. The technique selected is determined by factors such as the system's characteristics, the availability of data, the research's objectives, and the research's constraints.

There are many potential goals and objectives for the water resources system, so the planner must pick the best one. The nature of the system necessitates the use of deductive reasoning processes that can eliminate irrelevant options and reduce thousands of metrics to a more manageable set. The same is true for water resource development projects, in terms of both planning and management. Regulations or principles are applied to reservoir management based on the quantity and timing of water that must be stored and released. The following are some of the most widely accepted reservoir operation principles for flood control and conservational uses in the context of single purpose, multipurpose, and system reservoirs. These suggestions are meant to serve as broad, overarching guidelines. For the proper operation of a reservoir or network of reservoirs, unique regulation schedules must be developed after all relevant factors have been considered.

This research uses Multi Objective Fuzzy Linear Programming to create an optimal reservoir operation model for the stage-I Jayakwadi reservoir on the Godavari River in Maharashtra (MOFLP). This problem is framed with two goals in mind—irrigation release and hydropower generation—along with a number of constraints, and is then solved in an iterative fashion. Using linear membership functions, the objective function is fuzzy-valued. With the exception of the goals, it is assumed that all other model parameters are discrete. MOFLP is used to find a happy medium by maximising both the fuzzified objectives and the level of satisfactions. Potential outcomes for varying degrees of decision-maker satisfaction with objective measures are generated using the MOFLP model. Also, the optimal policies were determined for various incoming conditions using MOFLP.

The study's overarching objective was to demonstrate how system analysis methods can be used to optimise water resources management in service of measurable goals. Given the shift in policy and the growth in the agricultural, industrial, and domestic sectors, any water resource system, whether currently in place or soon to be implemented, should be able to meet the demand. Traditional methods dominate the system for managing food resources. However, system analysis and mathematical optimization techniques have been found to be helpful. Educating the public about the benefits of innovative approaches to water resource problems is, therefore, crucial.

The following are some of the goals of this research.

- Development of a MOFLP model featuring both loose and hard constraints and a fuzzy objective function.
- The optimization model is used to analyse the efficiency of the Jayakwadi reservoir at its initial stage.

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- Decision-makers are given a plethora of options thanks to lingo's (Language for Interactive General Optimization) use in the development of optimal operating policies.

The functioning of dam reservoirs is an important factor in water management research and planning. The research compared the effectiveness of three policies for improving reservoir performance: the Standard Operation Policy (SOP), the Hedging Rule (HR), and the Multi-Objective Optimization (MOO). The point of MOO was to boost dependability metrics while simultaneously reducing exposure. Coordination of the equilibrium between the interests of stakeholders in conventional ecological operations is difficult. It was proposed that multiple parties work together to manage a reservoir. The results show that the value of coordinated operation decreased by 0.184, 0.469, and 0.886 in a normal year, a dry year, and an exceptionally dry year, respectively. Soil and Water Assessment Tool (SWAT) and HEC-ResPRM were used to model and optimise the Nashe hydropower reservoir operation in the Blue Nile River Basin. Stream flow into the reservoir was determined using the SWAT model, which accounted for both short- and long-term effects of LULC changes [1-4].

A nested method is presented for the generation of reservoir scheduling models. Scheduled operations at the Three Gorges-Gezhouba (TG-GZB) cascade reservoirs serve as the basis for this system. A five-level framework for efficient scheduling has been developed using this method. It is unrealistic to expect DRSs to be redesigned to account for every conceivable negative scenario. An 11-step process is provided for dynamically modelling the available features of a DRS. The proposed framework was found to be useful for locating major influences on system performance [5,6].

The reservoir system can be optimised with the help of LP. A LP model was implemented by Palmer and Holmes [7] in the Seattle Water Department's expert system for managing drought. During a drought, Randall et al. [8] analysed how a multi-state water resource system functioned. Although most reservoir systems are non-linear, LP demands that they be made linear. This includes the constraints and the objective function. For the short-term, annual operation of an irrigation reservoir, Chaves and Kojiri[9] developed a deterministic LP model. Jangareddy and Nagesh Kumar [10] developed a chance constrained LP model to account for unpredictable cash inflows. Approximating solutions is possible via successive LP (SLP), just as approximating non-linear functions is possible via linear functions. Examples of SLP's application to multi-reservoir optimization problems are provided by Chang et al. [11]. In [12], Akter and Simonovic used LP to develop a system-wide operational and strategic plan for Adelaide's head works. Using LP, Shi et al.[13] detail a process for optimising power generation from the Highland Lakes on the Lower Colorado River in Texas over the course of a day. Consequently, LP can only be used for solving problems involving linear functions. In some cases, the optimization result may be worth less if simplified.

Short-term hydropower generation optimization research by Leta et al. [4] and Ghanbari et al. [14] demonstrated that the problem could be solved by rewriting it with only linear constraints on outflow release and storage content. An additional approach to the reservoir operation problem is the so-called Dynamic Programming method. Biswas et al. [15] developed a model of irrigation for the management of temporary reservoirs. The model consists of a crop water allocation model and an operating policy model developed with deterministic dynamic programming. Arunkumaret al. [16] also developed a DP model to solve the problem of water delivery from two reservoirs to an irrigation district at once. Predicted information is updated in the model, including evapotranspiration from crops, evaporation from reservoirs, and inflows. Nasseri et al. [17] were the first to introduce fuzzy linear programming as a variant of traditional LP. After looking at LP problems with fuzzy objectives and constraints and presenting an FLP-like LP problem, we see that the min operator is a useful aggregator for these functions. Ren et al[18] .'s proposal to use parametric programming to solve FLP has proven to be the most well-liked approach. Using their method, the optimal answer to the problem can be determined for a wide range of parameter values. RossT. J. [19] provided an illustration of how to use linear membership functions to solve fuzzy linear problems. In this research, we focused on the specific scenario of a fuzzy member with a linear membership function. They investigated problems where the right-side and technological coefficient are the only two uncertain variables. In their presentation of a fully fuzzy linear programming approach for multifunctional reservoir operating rules, Regulwar, Gaurav, and Kamodkar[20–23] outlined a number of advantages. This study investigates and applies the completely fuzzy linear system, which is a fuzzy linear system with fuzzy coefficients and fuzzy variables, to the reservoir operating problem, in order to determine the optimal release strategy for the Jayakwadi reservoir, which is located in the state of Maharashtra in India. And then they presented a paper on how to derive multipurpose single reservoir release policies using fuzzy constraints. Despite significant progress, reservoir operation research has been incredibly slow to translate into actual practise, as pointed out by Chaudhari and Anand [24]. Simonovic discussed the issues with reservoir operation models and the solutions to make them more appealing to operators.

Intuitionistic fuzzy set theory is a variant of fuzzy set theory that incorporates rejection and acceptance probabilities in such a way that their sum is less than one [25]. Solution proposals for intuitionistic fuzzy optimization [26] typically involve re-framing the optimization problem in light of the degree of rejection of restrictions and values of the impractical objectives. To rank agricultural best management practises, a case study of South Texas is used to illustrate the utility of a multi-criteria decision-making model based on Attanassous Intuitionistic Fuzzy Sets (A-IFS) methodology [26]. The intuitionistic fuzzy optimization method proposed in [20] is widely recognised as a powerful optimization tool by researchers around the world. This strategy aims to maximise acceptance while minimising rejection; the current strategy [28] additionally minimises hesitation when accepting new information. In most cases, the optimal irrigation planning model cannot be found by solving the crisp multiobjective problem because the objective functions, restrictions, and variables are highly uncertain, imprecise, and ambiguous in nature and depend on a large number of uncontrolled parameters. Since non-membership in the fuzzy set is a complement of membership in the set, the maximum of the membership function will always minimise non-membership. Since the degree of acceptance and rejection are defined simultaneously and are not additive, intuitionistic fuzzy sets tend to yield superior results [29]. A computational method for solving a multiobjective linear programming problem using an intuitive fuzzy optimization model is presented. To investigate how the model makes use of belonging/not-belonging status, a comparison of the effects of linear and nonlinear membership functions is provided [30]. A fuzzy multi-objective intuitionistic nonlinear programming model is developed for irrigation planning in both dry and wet conditions. The model's ability to accommodate uncertainty and resistance provides guidance to decision-makers in alleviating water scarcity [31]. Intuitive fuzzy multi-objective linear programming problem is provided using triangular fuzzy numbers and mixed constraints. Several linear and nonlinear membership functions are used to transform the original problem into a crisp linear/nonlinear programming problem, which can then be solved using the appropriate crisp programming approach [32]. Intuitionistic fuzzy optimization, an extended form of fuzzy optimization, considers user satisfaction, model rejection, and uncertainty as performance metrics [33]. Expert system, belief system, and information fusion model applications should consider both the truth membership supported by the evidence and the falsity membership opposed to the evidence [34], even though this is outside the scope of the fuzzy set and interval valued fuzzy set. However, intuitionistic fuzzy sets, a generalisation of fuzzy sets, account for both true and false membership. However, intuitionistic fuzzy sets are the only ones capable of dealing with incomplete information; contradictory or ambiguous data cannot be processed. Neutrosophic sets explicitly quantify truth membership, indeterminacy membership, and falsity membership, and these three types of membership are completely separate from one another [35-38]. Many single valued neutrosophic set (SVNS) operations have been established, and investigations into their basic properties continue [39–42]. A new multiobjective optimization framework is proposed for use in a neutrosophic context. The proposed approach [43–45] can be used to simultaneously deal with indeterminacy and falsehood.

2. FUZZY SET THEORY

First introduced by Regulwar and Kamodkar, fuzzy sets permit a looser membership criterion. For data that does not neatly fit into predetermined categories, fuzzy set theory provides a solution (i.e., fuzzy). Any method or theory that relies on "crisp" definitions, such as classical set theory, mathematics, and programming, can be "fuzzified" by replacing them with those of a fuzzy set with more nebulous boundaries. The extension of crisp theory and analysis to fuzzy techniques is powerful in solving real-world problems, which invariably involve some degree of imprecision and noise in the variables and parameters measured and processed for the application. Fuzzy logic uses language variables such as "high," "middle," and "low" to represent a range of numbers. Since fuzzy logic allows for overlap, these categories can be mixed. For instance, a flow of 10 units could be partially or fully classified as either "baseflow" or "interflow." Fuzzy set theory encompasses a wide range of related disciplines, including but not limited to fuzzy logic, fuzzy arithmetic, fuzzy mathematical programming, fuzzy topology, fuzzy graph theory, and fuzzy data analysis. There are two names for collections of clearly defined pieces: classical and crisp. In any given situation, there exists a set called the universal set that always and forever includes all of the elements of all other sets under consideration. The characteristic function of the set A is a formal way to say whether or not an element of A is in the set.

$$X_A(x) = \begin{cases} 1 & \text{If } x \in A \\ 0 & \text{If } x \notin A \end{cases}$$

Similar to this, a fuzzy set A of a set X can be described as a set of ordered pairs, each containing a first element from X and a second element from the interval [0, 1], with exactly one ordered pair present for each of X.

$\mu_A(x): X \rightarrow [0, 1]$

2.1 FUZZY RESERVOIR OPERATION MODEL

The specific stages that are taken for modelling reservoir operation with fuzzy logic are as follows:

Sharp inputs like inflow, reservoir storage, and release are converted into fuzzy variables during step a) Input Fuzzification; step b) Fuzzy Operator Creation Based on Expert Knowledge Base; step c) Fuzzy Operator Application to Create Single Number Representing Each Rule's Premise; step d) Rule Implications Definition; and step e) Defuzzication.

The first step in creating a fuzzy reservoir operation model is determining the degree of membership functions. Fuzzification yields a fuzzy degree of membership, wherein the inputs are members of all relevant fuzzy sets via the member, and the output is typically between 0 and 1. Regardless of the variable being used, the input is always a precise numerical value. The fuzzy rule set is formulated using the accumulated wisdom of professionals. If the storage is low and the inflow is moderate in period t, then the release is moderate. The rule basis should always be developed using the existing expert knowledge on the specific reservoir. Once the inputs have been fuzzified, it is possible to determine the extent to which each premise for each rule has been met. if the rationale behind a particular rule is recognised. When a premise of a given rule consists of more than one part, a fuzzy operator can be used to reduce the number of possible outcomes down to a single one. However many membership functions are fed into the fuzzy operator, the output is always a single trust value. Operators in fuzzy logic, like AND and OR, abide by the rules of traditional two-valued logic. Depending on the context, the AND operator can be interpreted as either the conjunction (min) of classical logic or the product (prod) of its two parameters. The probabilistic OR (prob or) approach is an alternate form of the OR method that is analogous to the disjunction operation in classical logic. The outcome of implication takes the shape of a fuzzy set. This is defuzzified for application. A fuzzy set is used as the input for the defuzzification process, and the output is one distinct integer. The "centroid" evaluation, which yields the centre of the area under the curve, is a typical defuzzification technique. The "bisection" defuzzification method is another option; it provides the bisection of the output fuzzy set's base.

Algorithm for MOFLP

The following algorithm (for maximisation problem) can be used to solve the MOFLP model.

Step 1:

Find the best (Z_1^+ and Z_2^+) values and worst (Z_1^- and Z_2^-) values corresponding to the set (decision variables) of solutions (X*) for each objective (Z_1 and Z_2) when you solve the model as a Linear Programming (LP) problem.

Step 2:

Define a linear membership function $\mu_k(x)$ for each objective as

$$\mu_{z1}(X) = \begin{cases} 0 & Z_1 \le Z_1^- \\ (Z_1 - Z_1^-)/(Z_1^+ - Z_1^-) & Z_1^- \le Z_1 \le Z_1^+ \\ 1 & Z_1 \ge Z_1^+ \end{cases}$$

$$\mu_{z2}(X) = \begin{cases} 0 & Z_2 \le Z_2^- \\ (Z_2 - Z_2^-)/(Z_2^+ - Z_2^-) & Z_2^- \le Z_2 \le Z_2^+ \\ 1 & Z_2 \ge Z_2^+ \end{cases}$$

Step 3:

An equivalent LP problem (crisp model) is then defined as

Maximize λ

Subject to

$$\lambda \le \frac{(Z_1 - Z_1^-)}{(Z_1^+ - Z_1^-)} \quad \text{And}$$

$$\lambda \le \frac{(Z_2 - Z_2^-)}{(Z_2^+ - Z_2^-)}$$

And all the original constraint sets and non negativity constraints for X and λ.

Step 4:

Solve the LP problem formulated in step 3. The solution is λ (i.e., maximum degree of overall satisfaction) which is achieved for the solution X*. The corresponding values of the objective functions are Z_1^* and Z_2^* obtained and this is the best compromise solution.

2.2 CASE STUDY

The Godavari River runs the length of the Deccan Plateau, from the Western Ghats to the Eastern Ghats. It all starts 80.46 km from the Arabian Sea, in the Nasik district of Maharashtra. Godavari, which rises to a height of 1066.81 m and flows south and east across Maharashtra and Andhra Pradesh, finally empties into the Bay of Bengal 96.56 km below Rajamuhendry. The Jayakwadi dam is located on the Godavari River in the Aurangabad district of the Indian state of Maharashtra. The catchment area of the reservoir is 21,750 km2 in size. There are currently 2171 Mm3 of usable storage and a total of 2909 Mm3 available. There is a total installed capacity of 12 MW for generating electricity (pumped storage plant). An area of 1,41,640 acres under command is irrigated. Kharif receives 22% of the total, Rabi 45%, two seasons 28%, hot weather 3%, and perennial crops 4.5% of the total. The entire power generation system has a capacity of 12 MW (pumped storage plant). The total irrigable area within the command zone is 1,41,640 acres. Kharif receives 22% of the total irrigation, Rabi 45%, two seasons 28%, hot weather 3%, and perennial crops 4.5%. Stage-1 of the Jayakwadi Project Report proposes the construction of a dam over the Godavari River in the Paithan

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Tehsil of the Aurangabad district of Maharashtra, with a live storage capacity of 2170 cumec. The longest dimension of the dam is 9997 metres, and its greatest height is 37.73 metres (without the overflow). The dam has a discharge capacity of 18150 cumec, 27 radial gates measuring 12.50 by 7.9 metres, and an overflow section measuring 417 metres in length. A lined, left-bank canal, 208 km in length, receives water from the Paithan Dam and irrigates a 1,41,640 hectare (ICA) area in the districts of Aurangabad, Jalana, Parbhani, and Ahmednagar.. The index map is shown in figure 1.

Table 1 shows the maximum irrigation demand and 75% dependable inflow. 75% dependable monthly inflows are estimated using the Weibull plotting position formula.

Table 1: Maximum irrigation demands and 75% dependable inflow.

Sr no.	Months	Maximum irrigation demand Mm^3	75% dependable InflowMm^3
1	June	3.50	112.762
2	July	3.90	320.25
3	August	0.60	610.66
4	September	33.60	600.00
5	October	93.70	147.75
6	November	109.00	116.46
7	December	66.90	85.53
8	January	45.00	37.65
9	February	46.10	21.462
10	March	75.10	19.562
11	April	95.30	25.50
12	May	57.50	46.587

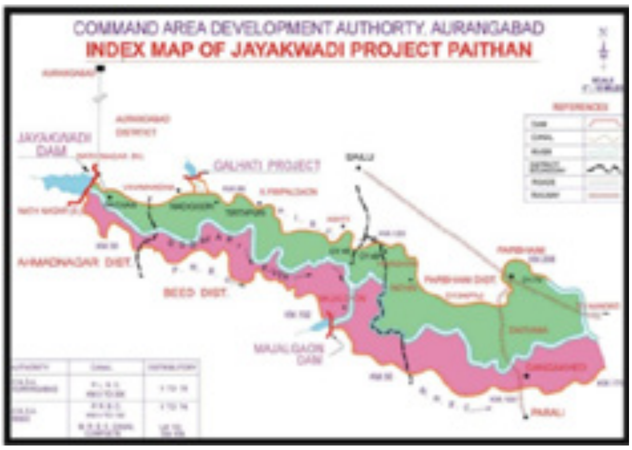

Figure 1. Index Map of Jayakwadi Project.

Formation of MOFLP model:

Application of MOFLP is demonstrate through the case study, Jayakwadi reservoir stage-1 in Maharashtra state, India. Problem is formulated with two objective function viz. Maximization of release for irrigation and maximization of release for hydropower production, with the following constraints and is solved in an iterative manner. All other model parameters other than the objectives are thought to be crisp in nature..

The study's two goals that were taken into account are:

(1) Maximization of release for irrigation (i.e., RI) and
(2) Maximization of release for hydro power production (i.e., RP)

Max Z_1 = Max (TOTRI)

Max Z_2 = Max (TOTRP)

where TOTRP is the total release for hydropower generation over all time periods, and TOTRI is the total release for irrigation over all time periods (i.e., months). These objective functions can written as

$$\text{MAX } Z_1 = \sum_{t=1}^{t=12} RI_t$$

$$\text{MAX } Z_2 = \sum_{t=1}^{t=12} RP_t$$

Constraint

Turbine release constraint

Each month's release for the amount of hydropower the turbine will produce (RP) must be greater than or equal to both the firm power (FP) committed for that month as well as the turbine's capacity (TC).

$RP_t \leq TC \qquad \forall t = 1, 2\text{.........}, 12$
$RP_t \geq FP_t \qquad \forall t = 1, 2\text{.........}, 12$

Irrigation demand constraint

Release into the canal for irrigation (RI) need to be lower than or equal to the demand for irrigation (ID). Release must also be more than the minimum amount of irrigation necessary for all time periods in order to prevent crop wilting (30% of the irrigation demand in this instance is regarded as the minimum irrigation requirement).

$RI_t \leq ID_t \qquad \forall t = 1, 2\text{.........}, 12$
$RI_t \geq 0.3ID_t \qquad \forall t = 1, 2\text{.........}, 12$

Reservoir storage capacity constraint

For all time periods, the reservoir's live storage should be below or equal to its maximum capacity (SCAP).

$S_t \leq SC \qquad \forall t = 1, 2\text{.........}, 12$
$S_t \geq S_{min} \qquad \forall t = 1, 2\text{.........}, 12$

Reservoir storage continuity constraint

These restrictions apply to all time periods' turbine release (RP), irrigation release (RI), reservoir storage (S), inflow (I) into the reservoir, overflows (O), and evaporation losses (L).

$S_t + I_t - RI_t + 0.9RP_t - O_t - L_t - FCR - RWS = S_{t+1}$

By considering the evaporation losses as a function of storage (Loucks et al., 1981) and by assuming a linear relationship between reservoir water surface area and storage, continuity constraint can be written as follows.

$(1\text{-}a_t)\, S_t + I_t - RI_t - RP_t + 0.9RP_t - FCR - RWS - O_t - A_o e_t = S_{t+1}$

Where,

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$a_t = A_A e_t / 2$

A_A = Surface area of the reservoir per unit active storage volume.

A_o= Surface area of the reservoir corresponding to the dead storage volume.

e_t= Evaporation rate for month t in depth units.

RWS = Release for water supply.

FCR = Feeder canal releases.

3. PERFORMANCE ANALYSIS

For the purpose of reservoir management, a Multi Objective Fuzzy Linear Programming (MOFLP) model has been created. By focusing on one goal at a time, the optimal and worst-case values (Z+ and Z-) for both objectives (Z1 for release for irrigation and Z2 for release for power production) can be calculated. LINGO is used to maximise irrigation water release and power generation water release (Language for Interactive general optimization). When Z1 is maximised, Z2 is assumed to have its worst possible value, and vice versa. These values are specified in table 2.

Table 2: Objective function values (Best and Worst).

Objective function (Maximization)	Best value (Z^+)	Worst value (Z^-)
Release for irrigation (Z_1) Mm³	630.20	392.0843
Release for Hydro-power Production (Z_2) Mm³	408.00	336.00

When Z1 (release for irrigation) is maximised, hydropower generation (Z2) receives less power. Maximizing hydropower generation, denoted by Z2, gives higher priority to releasing water for power generation than releasing water for irrigation, denoted by Z1. The Jayakwadi scheme uses a reversible turbine for its pumped storage. The weirs that store the excess water from the hydropower generation and release it to the turbines downstream are only used during peak demand. The water is pumped upstream from the downstream weir and into the reservoir during off-peak hours (midnight, for example) using the same turbine.

After the objective function's upper and lower LINGO bounds are established, the second step is to fuzzify the objective functions by considering a suitable membership function. In this analysis, we focus on membership functions that are linear in nature.

$$\mu_{x1}(X) = \begin{cases} 0 & Z_1 \le 392.0843 \\ \left(\dfrac{Z_1 - 392.0843}{630.20 - 392.0843} \right) & 392.0843 \le Z_1 \le 630.20 \\ 1 & Z_1 \ge 630.20 \end{cases}$$

$$\mu_{x2}(X) = \begin{cases} 0 & Z_2 \le 336.00 \\ \left(\dfrac{Z_2 - 336.00}{408.00 - 336.00} \right) & 336.00 \le Z_2 \le 408.00 \\ 1 & Z_2 \ge 408.00 \end{cases}$$

The membership function for both the objectives Z_1 and Z_2 are shown in figures 2 and figure 3 respectively and can be stated as follows.

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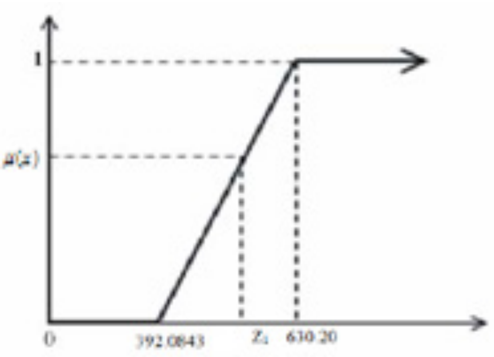

Fig.2 Membership function for Z_1.

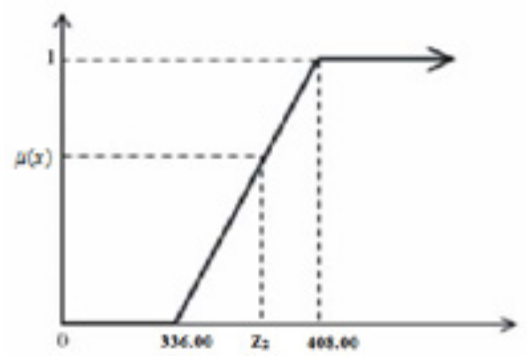

Fig.3 Membership function for Z_2.

The following updated LP problem is created as the third phase of the algorithm by combining the information mentioned before. Coefficients for constraints given below are obtained from the above two equations.

Maximizeλ

Subject to

$$\lambda \leq \frac{Z_1 - 392.0843}{630.20 - 392.0843}$$

$$\lambda \leq \frac{Z_2 - 336.00}{408.0 - 336.00}$$

And all the original constraints given in the model and $\lambda \geq 0$

The amount of satisfaction obtained by simultaneously optimising the fuzzified objectives Z1 and Z2 is represented by the symbol λ in this formulation. In the following stage, the LP model's solution is discovered.

The result obtained as follows.

λ (Maximum level of satisfaction = 1.00)

Z_1^* (Release of irrigation at the maximum level of satisfaction) = 630.20

Z_2^* (Release for Hydro power production corresponding to maximum level of satisfaction) = 408.00

The operating policy for maximization of release for irrigation is given in table 3 and maximization for power production is given in table 4. The operating policy corresponding to maximum level of satisfaction is given in table 5 and the results are shown in graph.

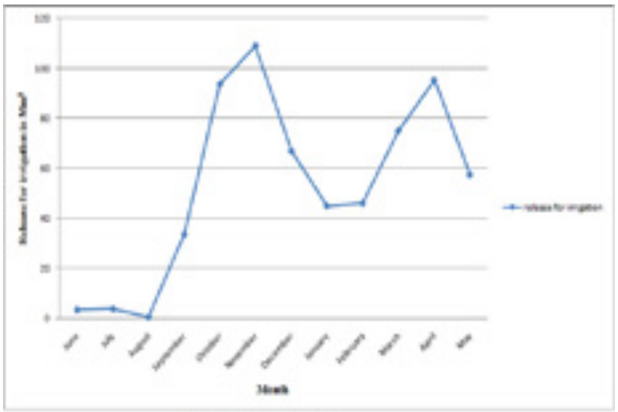

Figure 4. Release for irrigation (for maximization of Z_1).

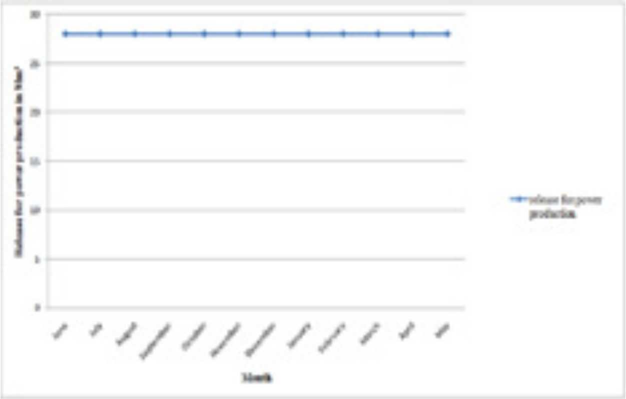

Figure 5. Release for power production (for maximization of Z_1).

Table 3: Operation policy for maximization of release for irrigation.

Month	Irrigation releases (RI) Mm^3	Turbine releases (RP)Mm^3	Head over turbine M	Storage Mm^3	Overflow Mm^3	Water supply releases Mm^3	FCR Mm^3
June	3.50	28.00	25.59	948.41	0.00	30.00	0.00
July	3.90	28.00	25.99	959.15	0.00	30.00	0.00
August	0.60	28.00	27.26	1187.225	0.00	30.00	0.00
September	33.60	28.00	28.94	1706.20	0.00	30.00	0.00
October	93.70	28.00	29.57	2170.599	0.00	30.00	50.00
November	109.00	28.00	29.15	2080.928	0.00	30.00	80.00
December	66.90	28.00	28.68	1924.644	0.00	30.00	70.00
January	45.00	28.00	28.17	1802.826	0.00	30.00	90.00
February	46.10	28.00	27.60	1626.343	0.00	30.00	60.00
March	75.10	28.00	27.03	1465.273	0.00	30.00	0.00
April	95.30	28.00	26.37	1288.857	0.00	30.00	0.00
May	57.50	28.00	25.80	1081.303	0.00	30.00	0.00
Total	**630.20**	**336.00**	**330.15**	**18241.758**	**0.00**	**360.00**	**350.00**

Table 4: Operation policy for maximization of release for Hydro power production.

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Month	Irrigation releases (RI) Mm³	Turbine releases (RP) Mm³	Head over turbine M	Storage Mm³	Overflow Mm³	Water supply releases Mm³	FCR Mm³
June	3.50	34.00	28.32	1766.84	0.00	30.00	0.00
July	3.90	34.00	28.66	1752.17	0.00	30.00	0.00
August	0.60	34.00	29.86	1960.379	0.00	30.00	0.00
September	33.60	34.00	31.48	2461.784	0.00	30.00	0.00
October	93.70	34.00	32.06	2909.00	0.00	30.00	50.00
November	109.00	34.00	31.60	2805.272	0.00	30.00	80.00
December	38.7843	34.00	31.13	2636.895	0.00	30.00	70.00
January	15.00	34.00	30.69	2533.645	0.00	30.00	90.00
February	16.00	34.00	30.17	2374.729	0.00	30.00	60.00
March	26.00	34.00	29.67	2231.045	0.00	30.00	0.00
April	32.00	34.00	29.10	2076.413	0.00	30.00	0.00
May	20.00	34.00	28.57	1895.989	0.00	30.00	0.00
Total	**392.0843**	**408.00**	**361.31**	**27404.161**	**0.00**	**360.00**	**350.00**

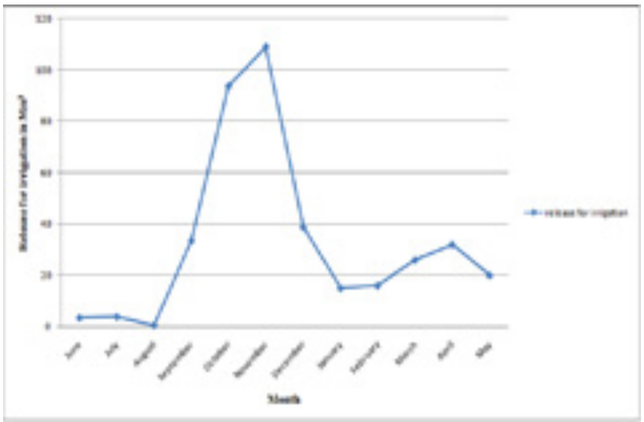

Figure 6. Release for irrigation (for maximization of Z_2).

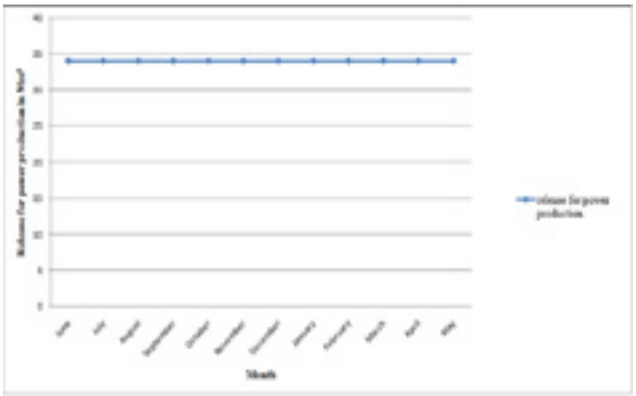

Figure 7. Release for power production (for maximization of Z_2).

Table 5: Operation policy for maximization of level of satisfaction i.e.λ = 1.00.

Month	Irrigation releases (RI) Mm³	Turbine releases (RP) Mm³	Head over turbine M	Storage Mm³	Overflow Mm³	Water supply releases Mm³	FCR Mm³

June	3.50	34.00	25.51	924.60	0.00	30.00	0.00
July	3.90	34.00	25.91	935.47	0.00	30.00	0.00
August	0.60	34.00	27.18	1163.530	0.00	30.00	0.00
September	33.60	34.00	28.85	1682.43	0.00	30.00	0.00
October	93.70	34.00	29.49	2146.759	0.00	30.00	50.00
November	109.00	34.00	29.07	2056.928	0.00	30.00	80.00
December	66.90	34.00	28.60	1900.43	0.00	30.00	70.00
January	45.00	34.00	28.10	1778.303	0.00	30.00	90.00
February	46.10	34.00	27.52	1601.624	0.00	30.00	60.00
March	75.10	34.00	26.94	1440.351	0.00	30.00	0.00
April	95.30	34.00	26.29	1264.189	0.00	30.00	0.00
May	57.50	34.00	25.71	1057.119	0.00	30.00	0.00
Total	**630.20**	**408.00**	**329.17**	**17951.733**	**0.00**	**360.00**	**350.00**

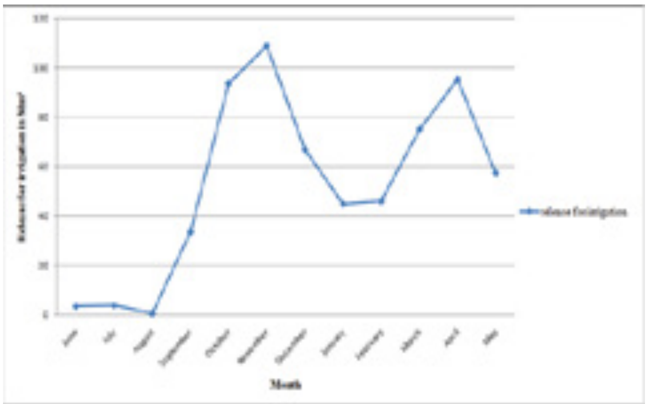

Figure 7. Optimal release for irrigation (for maximum satisfaction level).

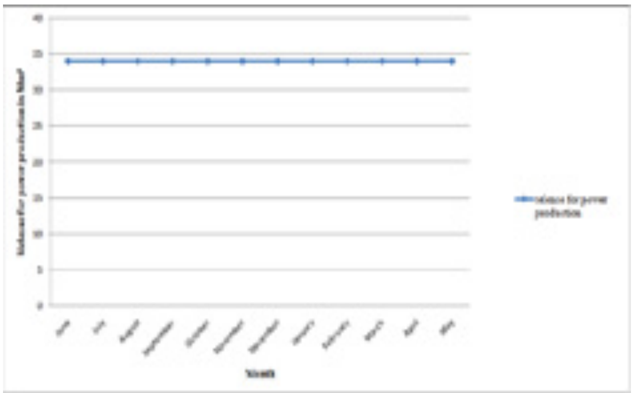

Figure 8. Optimal release for power production (for maximum satisfaction level).

Table 6: Maximized value of the objective function.

λ (Maximum level of Satisfaction)	**1.00**
Z_1^* (Irrigation release corresponding to the maximum level of satisfaction)	**630.20 Mm³**
Z_2^* (Release for Hydro power production corresponding to maximum level of satisfaction)	**408.00 Mm³**

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4. RESULT AND DISCUSSION

The fuzzy logic tool box available with the MATLAB package is used for developing the model(MATLAB).The inputs to the fuzzy system are inflows, storage, and time-of-year. The demand is assumed to be uniquely defined for a period, and hence the variable time-of-year(the period number) is taken as the equivalent input. The output is the release during the period. For the inputs and output operations the logical and implication operators are taken as (with conventional Fuzzy notation),

And Method = 'Min';
Or Method = 'Max';
Imp Method = 'Min';
Defuzz = 'Centroi

Where the 'And' and 'Or' method corresponds to the conjuction(min) and disjunc- tion(max) operation of classical logic.

Step 1) fuzzy inference system tool:

The membership functions are used to determine the degree to which the inputs belong to each of the relevant fuzzy sets as the initial stage in creating a fuzzy inference system. Fuzzy Controller has five Inputs and one output. A fuzzy degree of Membership is the final outcome of the fuzzification process, and the input is always a crisp numerical value constrained to the universe of discourse of the input variable. The storage, inflow, RWS, ID, Evaporation and release were assigned the triangular membership functions. The salient membership function for the input inflow and output power are shown in figure 9.

Input For Data

Membership function values are traced to 'very low', 'low', 'med', 'high', 'very high' of storage, inflow, RWS, ID, Evaporation and release membership functions, respectively.

Figure 9. FIS editor.

Step 2) Membership function for input and output

The following describes the broad context in which the creation of a membership function takes place. The scenario includes a knowledge engineer, one or more subject-matter experts, and a particular knowledge domain of interest. The responsibility of a knowledge engineer is to draw out relevant knowledge from specialists and convey it in a necessary sort of operational form. The knowledge

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engineer tries to extract information in the first step using propositions that are presented in plain language. The knowledge engineer makes an effort to ascertain the definition of each language term used in these statements in the second stage. The techniques used to build a membership function, as determined by experts.

Types of triangular membership functions should be used as input. To display the various input fuzzy variable ranges, the five membership functions "Very Low", "Low", "Medium", "High," and "Very High," are employed.

Output: (RI)

The appropriate fuzzy rule for the period is activated once the reservoir storage and inflow levels (high, medium, etc.) have been determined. A fuzzy set for the release is produced via the fuzzy operator, implication, and aggregation. The Centroid of the fuzzy set is then utilized to produce a crisp release.

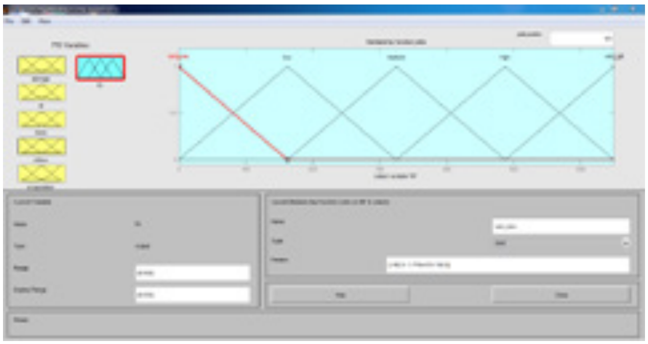

Figure 10. Membership Functions For Variables.

Step 3) Rule Viewer (adding and editing of rules):

The Rule Viewer is a show how the shape of certain membership functions influences the overall result. Rules shown in Rule Editor provide inference mechanism strategy and producing the control signal as output. Different numbers of rules that used in the system will give the different result, so the analysis for results will be conducted.

The operational rules were applied to generate a result for each rule before a combined operational rule were applied which then combines the results of the rules. These rules in figure 11 were applied to the inputs and the output of the Mamdani-type fuzzy inference system based controller. A new approach is therefore investigated through the use of fuzzy logic to serve as a base or platform to build an intelligent controller using a set of well-defined rules to guide its operational performance. By contrast, a fuzzy inference system employing "*if-then*" rules can model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analyses. It is necessary to defuzzify the output fuzzy set in order to receive the output of the whole set of rules as a single integer.

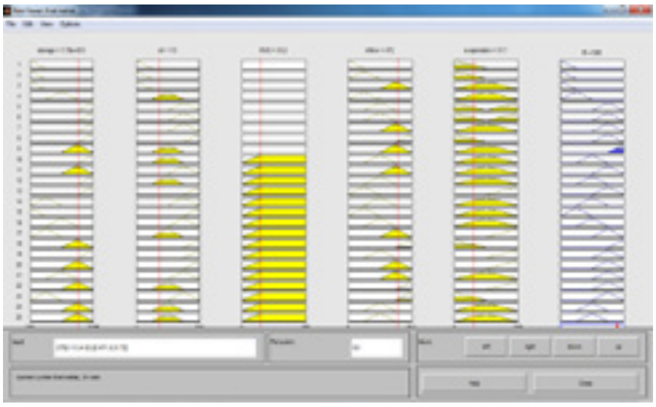

Figure 11. Generated Fuzzy Rules.

5. CONCLUSIONS

Application of system techniques to water management has gained momentum over the years. Many mathematical models have been developed and successfully applied for reservoir planning and operation studies. The use of these models has greatly aided in providing a good sight into the intricacies of the various aspects of problem in water management. The conclusions obtained from the present study of various are summarized. The Multi-Objective Fuzzy Linear Programming (MOFLP) model is created and employed to the reservoir operation problem to decide the optimal release policy for the Jayakwadi Reservoir stage-1, Maharashtra state, India. Optimal policies are determined for 75% dependable inflows using MOFLP. Depending on the decision-choice maker's of priorities for each target, these ideal policies may be put into practice for greater usage of the water resources. The two objectives i.e., release for irrigation and release for hydropower production are thought about in the study are maximization of irrigation release, and maximization of release for power production. First the model is solved for maximization of irrigation release. The maximized irrigation release obtained is 630.20 Mm^3 and corresponding release for power production 336.00 Mm^3. Then the model is run for maximization of release for hydropower production. The maximized release for hydropower production obtained is 408.00 Mm^3 and corresponding irrigation release is 392.0843 Mm^3.

The best and worst values of the two objective functions are decided. The objective functions are fuzzified over the best and worst values of each objective functions. The maximum satisfaction level for the fuzzified problem is obtained as 1.00. For this satisfaction level, maximized sum of release for irrigation is 630.20 Mm^3 and maximized sum of release for hydropower production is 408.00 Mm^3. Fuzzy rule based model considering singe objective is developed viz. release for irrigation. The model is based on the "if-then principle," where "if" represents a vector of ambiguous premises and "then" represents a vector of fuzzy consequences. Using mamdani method of FIS, the release for irrigation is 588 Mm^3.

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