OPTIMAL RESERVOIR OPERATION POLICY USING FUZZY LINEAR PROGRAMMING

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Abstract— India is densely populated country. Due to rapid growth of population and economic development, water is becoming a precious and scarce resource as a result of growing demands. In India, monsoon occurs between June and September. So the storage of rain water is important for economic growth. As the effect of it, reservoir system and water resource management has been developed. Reservoir systems have objectives like irrigation for multi crops, hydropower, water supplies, navigation, etc. The main advantage of reservoir storage is that the stored water can be used as per the requirement of crops, rather than depending on rainfall or nature. In reservoir operation, allocation is the main concept, to achieve the best possible performance of the system, decisions need to be taken on releases and storages over a period of time considering the variations in inflows and demands.

Water resource allocation problem can be solve by various techniques like, linear programming, dynamic programming, stochastic dynamic programming, nonlinear programming along with some fuzziness is consider at various level. To get the solution of such problems which consists of conflicting objectives effective optimization technique can be used to get the better output. In this study, the problem is solved by linear programming considering fuzziness in objective function and in irrigation demand. Fuzzy linear programming is implemented to get the optimal reservoir operating policies of the Karanjwan reservoir of Maharashtra state, India. The satisfaction level is obtained as 0.5058 and corresponding optimal releases for irrigation are 88.5124 Mm^3. The release policy of reservoir obtained by fuzzy linear programming are compared with linear programming.

Keywords— Reservoir optimization, Optimal operating policy, Fuzzy linear programming, linear programming, LINGO, etc.

I. INTRODUCTION

The essential role of science and technology in the development process has been demonstrated that India has adequate land and water resources to meet the entire requirement for projected population. So the development of optimal operating policies of the available water reservoir has been become an active area of research. The various techniques which developed the operating policies for reservoir operation have been explained in various articles. The Persoons et.al(2002) compare the reservoir operating policies which getting from fuzzy and non-fuzzy SDP, both the model gives same results but FSDP has its ability to explicitly capture water users and managers preferences, as well as the associated vagueness this was achieved by constructing membership function. Yeh (1985) found out the considerable progress relating to reservoir operation has been very slow in finding its way into practice, especially at the time of actual operation. Formulation of optimization models for reservoir systems are difficult to adapt to real system due to some institutional constraints. Dubrovin et.al (2002) built the fuzzy rules for reservoir operation by considering the variation in hydrological and operational targets. They gave the remark that the fuzzy logic calculation are straight forward and easy to operate.

The main aim in developing optimal reservoir operating policy lie in dealing with the complexity of typical systems, the uncertainty about the future rainfall and ultimately the inflow into the reservoir with uncertainty of releases for various purposes. The fuzzy logic approach provide a promising alternative to the methods used for reservoir operation modelling, as Russell and Campbell (1996) mentioned the fuzzy approach is more flexible and allows incorporation of expert opinion, which could make it more useful supplement to other conventional optimization techniques. Shrestha et.al(1996) confirm that fuzzy logic is an appropriate tool to consider the impreciseness of variables like inflows, in reservoir operation modelling, because it offer a way for operators to participate in the development of operating systems. When the constraints and /or the objective function are fuzzy, the methods proposed by Zimmermann (1978) are used more often than the others. It is possible that objective function is unbounded but Zimmermann presents a bounded solution as the optimal solution. ShrinivasaRaju and Nagesh Kumar (1997) have been developed FLP irrigation planning model for the evaluation of management strategies for the case study. Three conflicting objectives net benefits, agricultural production and labour employment were considered in irrigation planning. Nagesh Kumar et al. (2001) have used fuzzy logic approach for optimal reservoir operation. The FLP is used for the problem of water allocation under uncertainty using theory of fuzzy numbers.

Fuzzy logic approached preferable approach for the solution of complex problems. FLP can be solved by using linear membership function. The study has been concentrated on the case of FLP in which only right hand side i.e. resources are in fuzzy nature. In the present study fuzzy linear programming (FLP) model is develop for optimal operation of the reservoir, where the maximum irrigation demand is considered in fuzzy nature. The linear programming is converted into equivalent linear or non-linear programming problem by finding the lower and upper bound of the objective function and the problem is converted into linear membership function, and then after the problem is converted into classical optimization problem by introducing maximum level satisfaction (λ). The solution of the classical optimization problem gives the maximum level of satisfaction and from this; the optimal value of the objective function is obtained. The results from the FLP are compared with the results of the linear programming model for the same study area.

II. SYSTEM DESCRIPTION

The Karanjwan reservoir is constructed across the Kadwa river, tributary of Godavari river in Nashik district of Maharashtra state, India. It was constructed strictly for irrigation purpose. The Palkhed peak up weir which release the water for irrigation purpose is constructed at 24 km downstream of the main reservoir. It is located at Latitude of 20°18'44.28" N and Longitude of73°45'0.72" E. The gross storage capacity of 175 Mm^3 and live storage capacity of 166.22 Mm^3.

In this paper, Fuzzy linear programming model is form for the optimal operation of the reservoir. Also linear programming model is solved for a single purpose reservoir. Results from numerical experiments are presented, discussed and conclusions are drawn.

III. FUZZY LINEAR PROGRAMMING

Prof. Lotfi A. Zadeh introduced the seminal paper on fuzzy sets in 1965. Since then, many developments have been taken place in different parts of the world. In real world problem uncertainty can arises from many factors, such as complexity, randomness, ignorance or imprecision. So the concept of fuzziness arises. It is a language concept; its main strength is its vagueness using symbols and defining them.

The key ideas are that fuzzy logic allows for something to be partly this and partly that, rather than having to be either all this or all that; and that the degree of "belongingness" to a set or category. The degree of membership is expressed by a real number the interval [0, 1]. The difference between crisp (i.e. classical) and fuzzy set is established by introducing a membership function. Usually the membership function is made linear as this makes subsequent calculations easier. The objective then can be formulated as maximizing the minimum membership value, which has the effect of balancing the degree to which the constraints have to be relaxed from their optimal values.

In fuzzy linear programming problem basically three cases are discussed, first is right hand side i.e. resources are considered to be of fuzzy nature, secondly left hand side i.e. technological coefficients are considered to be in fuzzy nature and in third case both resources and technological coefficients are considered to be in fuzzy nature. Here in this study only right hand side number Bi are fuzzy numbers. General form is given below as,

$$\max \sum_{j=1}^{n} C_j X_j$$
$$s.t \sum_{j=1}^{n} A_{ij} X_j \leq B_i (i \in N_m)$$
$$X_j \geq 0, (j \in N_n)$$

Where, B_i are fuzzy numbers.

Fuzzy linear programming problem is converted into equivalent crisp linear or nonlinear problems by introducing Linear membership function G(x) as,

$$G(x) = \begin{cases} 1 & \text{Where } Zu \leq CX \\ \dfrac{Z - Z_l}{Z_u - Z_l} & \text{Where } Z_l < CX < Zu \\ 0 & \text{Where } CX \leq Z_l \end{cases}$$

For defuzzification of the problem, we first fuzzify the objective function. This is done by calculating the lower and upper bound of the optimal objective function. The good and worst value of the objective function i.e bound of the optimal values Z_u and Z_l are obtained by solving linear programming problem.

$$\max z_l = cx$$
$$s.t \sum_{j=1}^{n} a_{ij} x_j \leq b_i$$
$$x_j \geq 0$$
$$\max z_u = cx$$
$$s.t \sum_{j=1}^{n} a_{ij} x_j \leq b_i + p_i$$
$$x_j \geq 0$$

The objective function has the value between Z_u and Z_l while the resources i.e. right-hand-side varies from b_i to b_i+p_i. The Z_u and Z_l are called as upper and lower bound of the optimal values respectively. The above problem is converted into classical optimization problem as,

$$\max \lambda$$
$$s.t \lambda(z_u \quad z_l) \quad cx < \quad z_l$$
$$\lambda p_i + \sum^{n} a_{ij} x_j < b_i + p_i$$
$$\lambda, x \geq 0$$

Where, λ is the maximum level of satisfaction.

In the present study, FLP model is explained is implemented to Karanjwan reservoir. FLP reservoir optimization model is implemented to maximize releases for irrigation as objective function. An optimal operating policy has been decided by maximizing the level of satisfaction (λ) for objective.

The FLP reservoir operation model with corresponding constraints is briefly explained in next section.

IV. MODEL DEVELOPMENT

Following FLP model has been developed to get the monthly reservoir operating policy.

4.1. Objective function:

The objective of the study is to maximize the releases for irrigation purpose (i.e. RI_t).

$$\text{Max.}Z = \sum_{t=1}^{12} R_{1,t}$$

Where, RI_t is the releases for irrigation for the period between 1st month as June and to 12th month as May of the water year.

4.2. Constraints:

1. Irrigation Demand constraint

Releases which are provided for irrigation purpose should be less than or equal to the maximum irrigation demand(ID_{max}) and it is greater than minimum irrigation demand (ID_{min}) within the water year, maximum irrigation demand is considered as fuzzy in nature.

$$R_{1,t} \leq ID_{max} \quad \forall t = 1,2......12$$
$$R_{1,t} \geq ID_{min} \quad \forall t = 1,2......12$$

2. Storage capacity constraint

The capacity of the reservoir in the water year should be less than or equal to the gross storage (SC_{max}) capacity and it is greater than or equal to the dead storage capacity of the reservoir (SC_{min}).

3. Reservoir water balance equation.

The reservoir storage for the next month (S_{t+1}) is obtained by reservoir water balance equation which is calculated by considering the storage of the present month (S_t), inflow of the present month (I_t), release for irrigation for the present month ($R_{1,t}$), downstream water requirement for industrial purpose ($R_{2,t}$) of the present month, losses (L_t) due to evaporation and leakages from the reservoir and overflow (OVF_t) from the dam is considered, which is given by the equation as

V. RESULTS AND DISCUSSION

$$S_{t+1} = S_t + I_t - R_{1,t} - R_{2,t} - L_t - OVF_t \quad \forall t = 1,2......12$$

In case of Fuzzy Linear Programming, objectives have been considered as maximization of releases for irrigation (i.e. $R_{1,t}$). For defuzzification of the problem first fuzzify the objective function. The above discussed fuzzy linear programming problem is converted into equivalent crisp linear programming by calculating separately values of the upper (Z_u) and lower bound (Z_l) of the objective function. This FLP is solved in LINGO (Language for Intellectual General Optimization) by developing the code. The values of lower and upper objective function are found out by solving the linear programming problem. The Table 1 gives the upper and lower values of the objective functions.

Table 1: Best and worst values of the objective function

Objective function (Maximization)	Best value Z_u	Worst value Z_l
Releases for irrigation (Mm^3)	122.234	47.9496

From these values, upper and lower limit for the objective function are determined. After getting the upper and lower limits of the objective functions, then the objective function and constraint are fuzzified by considering suitable membership functions. In the present case study, linear membership functions are considered. Linear membership functions for objective and is shown in Figure 1 and for irrigation demand it is shown in Figure 2.

The maximum level of satisfaction i.e. λ= 0.5057 is obtained.

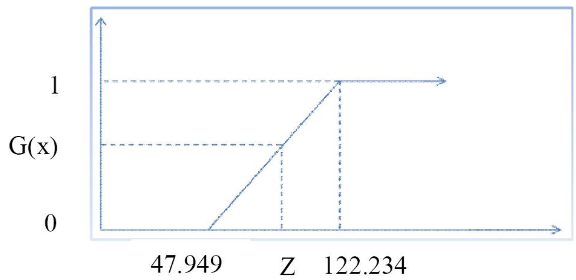

Fig.1. Membership Function for Z

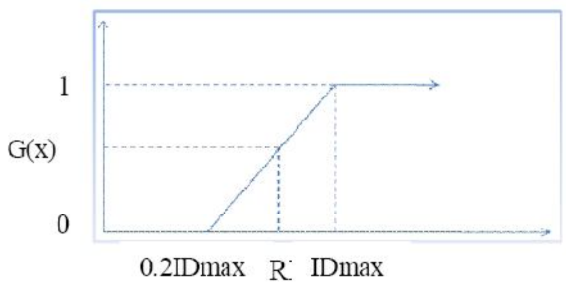

Fig.2. Membership function for irrigation demand

By incorporating above information, the following modified linear programming problem is formulated,

Max λ

Subjected to,

$((Z-47.9496)/(122.234-47.9496) \geq \lambda$,

$((ID-0.2IDmax)/ (IDmax-0.2IDmax) \geq \lambda$,

And all the remaining constraints and $0 \leq \lambda < 1$ are considered. In this problem formulation λ is the level of satisfaction. The results are obtained as follows,

λ= 0.50578, level of satisfaction and releases for irrigation as

$Z=R_{1,t}$as 88.5124 Mm^3

The table 2 shows the monthly release policy of the reservoir obtained by fuzzy linear programming and by Linear Programming (LP) for the present study area.

Table 2: Optimized Operating policy for Maximized Level of Satisfaction by FLP and by LP in Mm^3

Month	Release policy by FLP in Mm^3	Release policy by LP in Mm^3
June	8.27205	8.18826
July	0.166638	0.1222
August	0.128965	0.0668
September	0.22303	0.20609
October	13.8887	17.6032
November	10.40935	13.9321
December	18.63062	24.6244
January	1.800037	2.5411
February	7.153272	21.7941
March	13.39312	10.0023
April	7.176559	11.5115
May	7.270211	11.6422

The release policy obtained by fuzzy linear programming is compared with linear programming. It is observed that, the release policy given by linear programming is vague as it does not shows any optimal results. From June to September results of FLP and LP both are showing approximately same results. But the result of release policy from October shows large variation as linear programming gives more releases than the fuzzy linear programming. Release policy obtained by FLP help to satisfy the level up to 0.5057. Figure 3 shows comparison of release policy obtained by fuzzy linear programming and linear programming verses months in the water year.

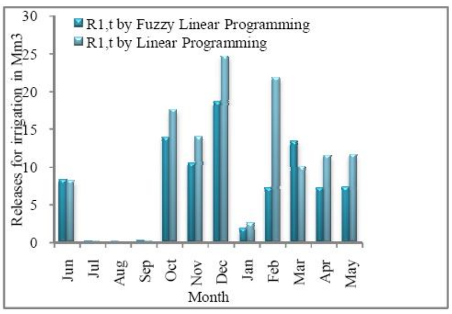

Fig.3. Month Vs Releases for irrigation by FLP and by LP

CONCLUSION

In the present study, reservoir system is controlled by application of fuzzy for few variables. Fuzzy logic can deal with the problem as per thinking power of human mind. Therefore, fuzzy logic programming is best alternative to other optimization techniques when uncertainty occurs. It introduces flexibility and responsiveness to existing operating system as well as way of fine-tuning them. Fuzzy linear programming is implemented to Karanjwan reservoir of Nashik district, Maharashtra state, India. The uncertainty of the problem is handling by membership function in FLP. Analysis of the results shows that FLP model gives better results as 50.58% when compared to the ideal values of crisp linear programming model along with level of satisfaction of 0.5058. SO it is concluded that, fuzzy linear programming is simple and suitable technique for problems which included the uncertainty in the parameters.

REFERENCES

[1] W. Yeh, W. G., "Reservoir management and operation models: A state of the art review", Water Resour. Res. Vol.21, issue 12, pp.1797–1818, 1985.

[2] L. A. Zadeh, "Fuzzy sets, Information and Control", Vol.8, pp.338–353

[3] H.J. Zimmermann, "Fuzzy Programming and Linear Programming with Several Objective Functions.Fuzzy Sets and Systems".Vol. l, pp. 45-55, 1978.

[4] P.F. Campbell, "Applications of fuzzy set theory in reservoir operation", 1993

[5] G.J. Klir and T. A. Folger, "Fuzzy sets, Uncertainty, and Information", 4th edition, Prentice Hall of India Limited, 1995.

[6] S.O. Russeland P.E. Campbell, "Reservoir operating rules with fuzzy logic programming", J. Water Resour. Plann.Manag.Vol.122, issue 3, pp. 165–170, 1996.

[7] B.P. Shrestha, L.Ducksteinand E.Z. Stakhiv, "Fuzzy rule based modeling of reservoir operation", J. Water Resour. Plann.Manag.Vol.122, issue 4, pp.262–269. 1996.

[8] R.K. Srinivasaand D. Nagesh Kumar, "Irrigation Planning of Sri Ram Sagar Project using Multiobjective Fuzzy Linear Programming".Journal.OfHydraulic Engineering, Indian Society for Hydraulics, Vol. 6, No.I, pp. 55-62, 2000.

[9] D. Nagesh Kumar, D.S. V. Prasad and K. SrinivasaRaju, "Optimal Reservoir Operation using Fuzzy Approach". Proc. of International Conference on Civil Engineering.(ICCE-200 I), Banglore, India, Vol. II. Interline Publishing. pp. 373-384, July 23-25, 2001.

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