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# Fuzzy Rule Based Model for Optimal Reservoir Releases

Dr. T. M. V. Suryanarayana[1], Mihir Kemkar[2]
[1] (Associate professor, Water Resources Engineering and Management Institute, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Samiala-391410, Vadodara, Gujarat, India
[2] (P.G. Student, Water Resources Engineering and Management Institute, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Samiala-391410, Vadodara, Gujarat, India

***Abstract:*** *The aim of this paper is to develop a Fuzzy Rule Based(FRB) model for obtaining the optimal reservoir releases. The area considered for the study is ukai reservoir project. The data considered are for the months of July, August, September and October for the years 2007 and 2011. The inputs considered are inflow (MCM), Storage (MCM), Demand (MCM) and the Release (MCM) is considered as output. Fuzzy logic, analysis is based on designing of if and then rules. Fuzzy logic model can handle with various kinds of data regulations implication and defuzzification. The steps involved in the development of the model include the construction of membership functions, creating the Fuzzy rules, implication and deffuzification. The results obtained shows that the releases obtained from the FRB model are satisfying the demand completely in all the four months, i.e. July, August, September and October for the year 2007 and the same is observed for the year 2011. Also, a significant amount of water is being saved, when the actual releases are compared with the releases obtained from the FRB model.*

***Keywords:*** *Fuzzy rules, Membership functions, Optimal release, Optimization, Reservoir operation, Ukai reservoir project.*

## I. INTRODUCTION

Risk and uncertainty always remain as one of important issues due to lack of future knowledge information that leads to achieve the planning goals precisely, therefore, recognizing future uncertainty helps to decrease the risks and increase the benefits, however, even with development of mathematical and computational techniques, finding an exact deterministic solutions still skeptical. Reservoir operation is not exception, hence any reservoir operation problem contains some degree of uncertainty and ambiguity due to several involved components, Reservoirs are built usually to serve multiple purposes for example irrigation, municipal and industrial water supply, hydro-power and flood control. Fuzzy systems are an alternative to traditional notions of set membership and logic that has its origins in ancient Greek philosophy, and applications at the leading edge of Artificial Intelligence. Optimal operation of reservoir has been an active area of research for many years The fuzzy logic approach may provide a promising alternative to the methods used for reservoir operation modeling, The uncertainty of water resources systems due to parameters inputs randomness can be handled adequately using probability theory in case of sufficient data availability, while the uncertainty that attributed to imprecision can be solved appropriately using the capability of fuzzy set theory that allowing to translate the human experience in mathematical forms taking the shape of memberships functions. Panigrahi and Majumdar [1] developed a fuzzy rule based model for the operation of a single purpose reservoir. The model operates on an 'if – then' principle, where the 'if' is a vector of fuzzy premises and the 'then' is a vector of fuzzy consequences. Mousavi et al. [2] developed a dynamic programming fuzzy rule–based (DPFRB) model for optimal operation of reservoirs system. This method results in deriving the operating policies, which are robust against the uncertainty of inflows. These policies are derived by using long-term synthetic inflows and an objective function that minimizes its variance. The DPFRB performance is tested and compared to a model, which uses the commonly used, multiple regression–based operating rules. Results show that the DPFRB performs well in terms of satisfying the system target performances and computational requirements. Bai and Tamjis [3] developed a fuzzy logic model for deriving optimal operational rules at the macro level for better performance and control of hydro-power generation. Mohan and Sivakumar [4] developed a heuristic Dynamic Programming based Neuro-Fuzzy Model (DPNF to optimize the operation of a multi-reservoir using dynamic programming and Adaptive Neuro Fuzzy Inference Systems (ANFIS) techniques. The demonstrations of developed models are carried out through application of Parambikulam AliyarProject (PAP) systems in India. Abdullah and Stamm [5] developed a Fuzzy Rule Based (FRB) membership functions depending on statistical parameters of time series analysis accompanied with different future climate change perspectives for inflow scenarios at the Eastern Nile region, while a statistical analysis and expert opinions have been used to shape the different storage, releases, and demands membership functions in order to obtain the optimum release.

## II. MODEL FORMULATION

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without crisp or clearly defined boundary. It can contain elements with only a partial degree of membership. The fuzzy inference process known as Mamdani's fuzzy inference method is used in this study. It's the most commonly seen fuzzy methodology. All output membership functions are singleton spikes, and the implication and aggregation method are fixed and cannot be edited.

A fuzzy rule based model operates on "IF-THEN" principle, where "IF" represents the vector of fuzzy explanatory variable, and "THEN" the fuzzy consequences, to apply this principles efficiently, a Fuzzy Inference System (FIS) is a control system built using fuzzy set theory based on combining the fuzzy sets from each rule through aggregation operator to get a fuzzy set result, then defuzzify the fuzzy set for each output variable. Two types of (FIS) can be applied in fuzzy logic, the most commonly and widely used Mamdani type (1977) and Takagi Sugeno type (1985); both methods are similar in many aspects; however the main difference between them is the output membership functions (MF) in Sugeno type are linear or constant. Since the output membership functions in this paper (namely reservoir release) are not necessarily linear, the FIS Mamdani has been adopted as it represents the output (release) more realistically.

1. Input and output variables fuzzification using convenient linguistics subsets such as high, medium, low, etc.
2. Based on expert knowledge and available information, IF-Then rules constructed to combine the linguistic inputs subsets to the output fuzzy sets using the logical conjunction such as "and".
3. The implication part of fuzzy system is defined as the shape of the consequent based on the premise (antecedent) part.
4. Finally, to have a crisp value, the resulted fuzzy set is defuzzified using the appropriate defuzzification method such as centroid.

The inputs to the fuzzy system are inflow (MCM), storage (MCM) and demand (MCM) for the reservoir. The output is the optimal release from the reservoir. The model is developed in the MATLAB.
The main objective of the study is to compute the quantity of the water that should be released to meet the monthly irrigation demand and also an attempt has been made in developing the model that obtained optimal releases from the FRB model should be less than actual releases of the reservoir while satisfying the demand completely.

To apply Fuzzy Rules to the above formulated model, the data used are inflow, demand, actual release, and storage in MCM. In modeling of reservoir operation with fuzzy logic, the following distinct steps are followed: (a) Fuzzification of inputs, where the crisp inputs such as the inflow, reservoir storage and release, are transformed into fuzzy variables, (b) Formulation of the fuzzy rule set, based on an expert knowledge base, (c) Application of a fuzzy operator, to obtain one number representing the premise of each rule, (d) Shaping of the consequence of the rule by implication, and (e) Defuzzification. The study area considered for developing the FRB model is ukai Reservoir project, Gujarat, India. The data comprises for the months of July, August, September and October for the years 2007 and 2011.

## III. Results and Discussion

The developed Fuzzy Rule Based (FRB) model gives the optimal releases for the data considered for the study.

Table 1: Actual release, Demand and Releases from FRB 2007

| Year | Month | Actual Release (MCM) | Demand (MCM) | **Releases from FRB model** |
|---|---|---|---|---|
| 2007 | July | 3135.12 | 2508.09 | **2510** |
| | August | 2912.65 | 1336.84 | **1500** |
| | September | 1696.92 | 1720.84 | **1790** |
| | October | 499.46 | 505.79 | **529** |

Table 1 shows the obtained optimal releases from FRB model for the months of July, August, September and October respectively for the year 2007, it is also given in Fig.1.

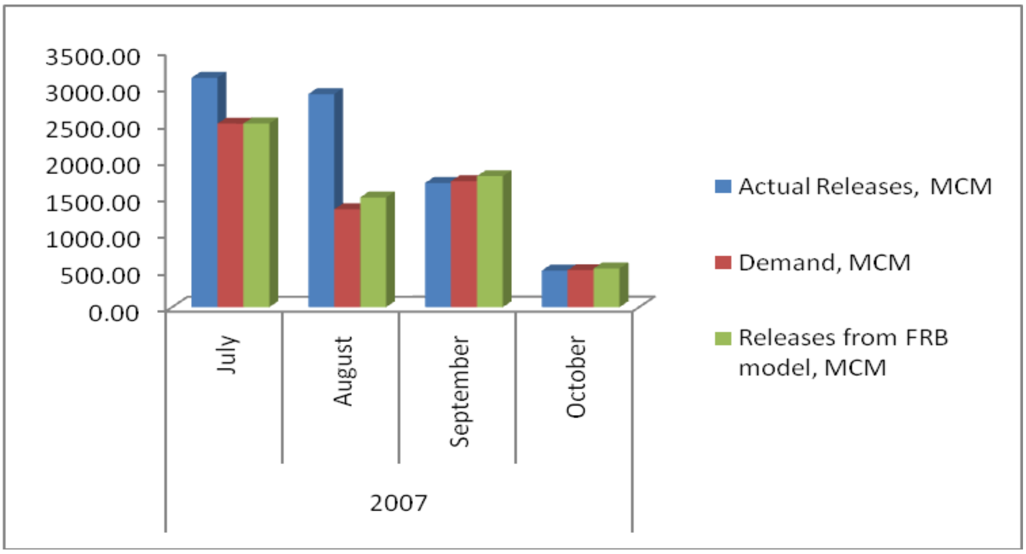


Fig. 1: Actual release, Demand and Releases from the FRB model for the year 2007

From Fig. 1, it is observed that releases obtained from FRB model are satisfying 100% demand in all the four months i.eJuly, August, September and October for the year 2007. Also a significant amount of water is being saved when actual releases are compared with the releases from the FRB model. In case of September and October although releases obtained from the FRB model are greater than the actual releases, but the actual releases were not satisfying demand for those two months.

The results obtained for the year 2011 are shown in Table 2

Table 2: Actual release, Demand and Release from FRB 2011

| Year | Month | Actual Release (MCM) | Demand (MCM) | **Releases from FRB model** |
|---|---|---|---|---|
| 2011 | July | 151.93 | 335.69 | **340** |
| | August | 1754.43 | 1403.54 | **1500** |
| | September | 1770.86 | 1530.89 | **1540** |
| | October | 353.00 | 200.7 | **293** |

Table 2 shows the obtained optimal releases from FRB model for the months of July, August, September and October respectively for the year 2011, it is also given in Fig. 2.

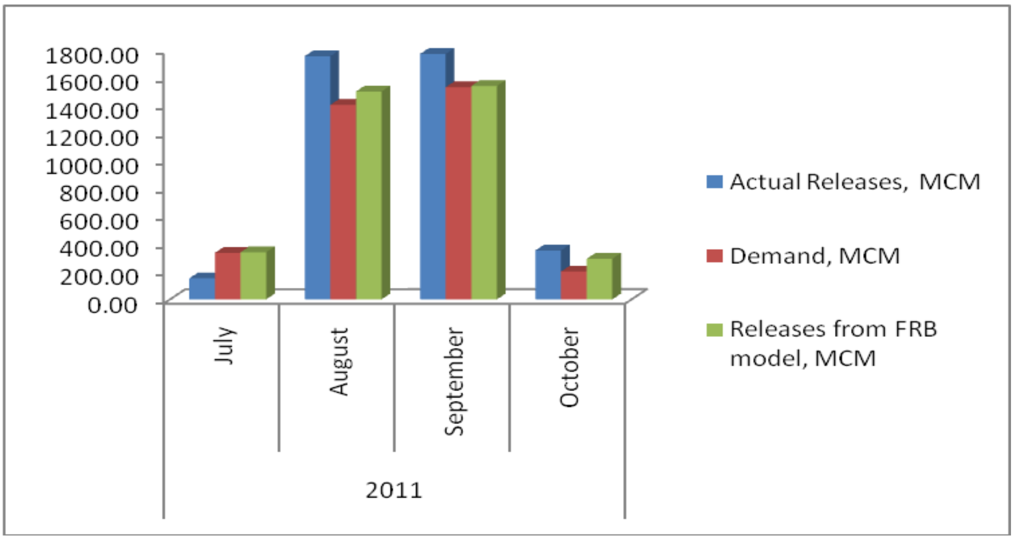


Fig. 1: Actual release, Demand and Releases from the FRB model for the year 2007

From Fig. 2, it is observed that releases obtained from FRB model are satisfying 100% demand in all the four months i.e. July, August, September and October for the year 2011. Even though in the month of July releases from FRB model are greater than actual releases, but actual releases were not satisfying demand. Also it is observed that in all four months model developed is saving significant amount of water and at the same time care has been taken for satisfying the demand completely.

## IV. CONCLUSION

It can be concluded that the FRB model yields the optimal releases for all the four months considered for the study i.e. July, August, September and October for the years 2007 and 2011. It has been found out that the obtained optimal release from the FRB model for the year 2007, in case of September and October and for the year 2011, in case of July FRB releases are greater than the actual releases but the care has been taken to satisfy the demand and in some cases, a significant amount of water is being saved when the actual releases are compared to the FRB releases.

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