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Research paper

Optimal multiobjective reservoir operation with fuzzy decision variables and resources: A compromise approach

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Abstract

Imprecision is often involved in reservoir-systems operation, as these systems are too complex to be defined in precise terms. Fuzzy programming has an essential role in fuzzy modeling, which can formulate uncertainty in the actual environment. In this study, a multipurpose, single-reservoir operation model is developed by assuming triangular fuzzy-number distribution of the parameters. The applicability of the model is demonstrated through the case study of the Jayakwadi reservoir stage II, Maharashtra State, India. The reservoir-operation model considers two objectives: maximization of the releases for irrigation and maximization of the releases for hydropower generation. The model is solved for a vector of a triangular fuzzy-number by giving a priority to each objective. By individual optimization, the fuzzy optimal solution is obtained for each objective in the form of a triangular fuzzy-number distribution. This solution is defuzzified to obtain the crisp values, which are further used to develop a fuzzy-compromised model. The compromised model is solved for the maximization of the degree of satisfaction (λ) by simultaneously optimizing both of the objectives. The degree of satisfaction (λ) achieved is 0.67, and the corresponding values for irrigation releases and hydropower releases are equal to the 388.54 Mm^3 and 195.19 Mm^3, respectively.

Keywords: Triangular fuzzy number; Fuzzy optimal solution; Defuzzification; Reservoir operation

1. Introduction

The occurrence of fuzziness in the real world is inevitable, owing to unexpected situations. Therefore, imposing fuzziness upon conventional optimization problems becomes an interesting research topic. Fuzzy linear programming (FLP) was first introduced by Zimmermann (1978), but the concept of fuzzy decision-making was first proposed by Bellman and Zadeh (1970). Wu (2008) has derived optimality conditions for linear programming (LP) problems with fuzzy coefficients. Two solutions are proposed by considering the ordering of the set of all fuzzy numbers. Buckely (1995) proposed a new solution concept for FLP. He defined and obtained the basic properties of the joint solution (a fuzzy vector R^n) and the optimal value of the objective function (a fuzzy number). A fuzzy, multiobjective linear-programming (MOLP) model was presented by Iskander (2008), which dealt with the fuzzy objective functions and the fuzzy constraints. The coefficients of the decision variables in the objective functions and constraints, as well as the right-hand side of the constraints are assumed to be fuzzy numbers with either trapezoidal or triangular membership functions. Rommelfanger (1996) has given a detailed survey on methods for solving fuzzy linear systems. First, LP model with soft constraints are discussed. Then, LP problems in which coefficients of constraints and/or of the objective function may be fuzzy are outlined. Gasimov and Yenilmez (2002) have solved FLP problems with linear membership functions. Nasseri (2008) has used vector computations on fuzzy vectors, in which a fuzzy vector appears as a vector of triangular fuzzy numbers. Jimenez et al. (2007) has

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proposed a method for solving LP problems, in which all of the coefficients are in general fuzzy-numbers. They have used a fuzzy ranking method to rank the fuzzy objective values and to address the inequality relation on constraints. Li et al. (2006) have developed a methodology for computing efficient solutions to fuzzy, multiobjective linear programming problems. In this study, they have improved the fuzzy-compromised approach of Guu and Wu (1999) by automatically computing the proper membership thresholds instead of choosing them. Wang and Wang (1997) have studied the MOLP problem with fuzzy-number cost coefficients. Based on the membership function, the problem is transformed into a multiobjective problem with a parametric-interval-valued MOLP problem. A two-phase procedure is introduced to solve multiobjective, fuzzy linear programming problems by Arikan and Gungor (2007). The procedure provides a practical solution approach, which is an integration of fuzzy parametric programming (FPP) and FLP.

Kamodkar and Regulwar (2010) have developed an FLP reservoir operation model in which the releases for various demands, storages in the reservoir in all time periods and objectives are considered fuzzy. Afshar (2012) adopted the particle swarm optimization (PSO) algorithm for the solution of large-scale reservoir operation problems with a release volume used for the decision variables of the problem. Labadie (2004) has given a state-of-the-art review for the optimal operation of multireservoir systems. The purpose of this review is to access the state-of-the-art in optimization of reservoir system management and operations and to consider future directions for additional research and applications. SrinivasaRaju and Nagesh Kumar (2000) demonstrated the way in which vagueness and imprecision in the objective function values can be quantified by a membership function in a fuzzy multiobjective framework. Nagesh Kumar et al. (2001) have developed an optimal reservoir model using multi objective fuzzy linear programming (MOFLP). The linear membership functions are used to fuzzify the objective functions. Only the objectives are taken to be fuzzy, and all other parameters of the model are considered to be crisp in nature. Unfortunately, in the real world, most of the parameters used are uncertain. Therefore, even if the LP formulation is accepted, neither the constraints, nor the revenues, can be characterized by certainty. Recent research in modeling uncertainty in water resource systems has highlighted the use of fuzzy logic-based approaches (Mujumdar and Ghosh, 2008). The uncertainty in reservoir operation parameters is considered by Regulwar and Kamodkar (2010) by treating them as a fuzzy set. This study is devoted to the identification of three different policies using three FLP models. The uncertainties can be tackled by formulating the problem of irrigation planning as FLP. FLP models can incorporate the scenario of the real-world problem of irrigation planning (Regulwar and Gurav, 2011).

Gurav and Regulwar (2012) proposed the MOFLP model, which addresses the fuzziness in resources and decision variables, which is closer to the real-world situation. The approach presented in the MOFLP model attempts to consider the fuzziness of all of the coefficients of a mathematical model, as they present themselves in real-life situations (Regulwar and Gurav, 2012). Regulwar and Anand Raj (2008) developed a 3D optimal surface for the operation policies of a multireservoir in a fuzzy environment using a genetic algorithm (GA) for river basin development and management. A multiobjective, multireservoir operation model for the maximization of irrigation releases and the maximization of hydropower production is proposed using GA. These objectives are fuzzified and simultaneously maximized by maximizing the level of satisfaction (λ). Regulwar and Anand Raj (2009) have studied multiobjective, multireservoir optimization in a fuzzy environment for river basin development and management. A model is proposed using GA in a fuzzy environment. The optimal operation policy obtained by the model is compared with the actual average operation policy for Jayakwadi reservoir stage I. The operations of a complex system of a multireservoir with multiple objectives have been demonstrated by Chaudhari and Anand Raj (2009). The multireservoir system includes uncertainties of the inflows and demands to the large extent. Fuzzy set theory has been proven as a robust theory in which these types of uncertainties have a major role.

In the literature, a number of researchers have applied fuzzy programming to the reservoir operation model to decide the optimal operating policy using a fuzzy-logic approach. However, many of them have addressed uncertainty either in the resources or the technological coefficients. Furthermore, the uncertainty in the inflows and various storage states of the reservoir are addressed by a linear membership function. In this study, an attempt has been made to address the uncertainty in the variables, resources and objective function of the reservoir-operation model. The uncertainty is defined by a triangular fuzzy-number and the fuzzy optimal solution is obtained for each objective, which is further defuzzified to develop a fuzzy-compromised model. The fuzzy-compromised model is solved for the maximized degree of satisfaction (λ) and by simultaneous optimization of both of the objectives. The applicability of the model is demonstrated through the case study of the Jayakwadi reservoir stage II, built across the river Sindaphana in Maharashtra State, India, to obtain the optimal release policy.

2. Methodology

Multiobjective reservoir operations are generally complex, as they are often associated with a large quantity of uncertain factors in combination with noncommensurable objectives. Water-resources systems must be planned by considering uncertain inputs.

In the present study, the reservoir operation model is developed by addressing the uncertainty in the various model parameters. These parameters are the releases for the irrigation, releases for the hydropower generation, irrigation demands, hydropower demands and the storage in the reservoir in any time period t and the storage capacity of the reservoir. Due to these uncertainties in the model parameters, the objectives of the model also become fuzzy, which has been